S·A·E JOURNAL

NOVEMBER 1931

S·A·E· JOURNAL

Published by the Society of Automotive Engineers, Inc., 29 *W. 39th St., New York*
Cable Address: Autoeng *Telephone:* Longacre 5-7170

Vincent Bendix, *President* John A. C. Warner, *Secretary* C. W. Spicer, *Treasurer*

Vol. XXIX November, 1931 No. 5

CONTENTS


ON THE AIRWAYS TODAY
as on the highways
for the last 30 years!
"Guaranteed Forgings"
WYMAN-GORDON
Worcester, Mass, and Harvey, Ill.

Producers Plan for Prosperity

No Depression of Ideas at Production Meeting in Detroit

AN OPTIMISTIC production man, attending the Society's 10th National Production Meeting in Detroit on Oct. 7 and 8, remarked that the sessions were of better than standard quality and that they were apparently not depressed by subnormal times and the presence of an undertakers' convention at the Book-Cadillac Hotel. Three lively technical sessions were held, a plant visit to the Holley Permanent Mold Machine, Inc., was enjoyed, and a first-class banquet climaxed the meeting on the evening of Oct. 8.

Joseph Geschelin, Chairman of the Production Activity Meetings Committee, set the opening session in motion by introducing J. C. Lincoln, of the Lincoln Electric Co., who acted as Chairman of the session.

Flash-Welding Body Sheets

Welding in the production of all-steel bodies for passenger automobiles was the subject treated in the single paper presented at this session. The paper was written jointly by Joseph W. Meadowcroft, assistant works manager, and James J. Paugh, welding engineer, of the Edward G. Budd Mfg. Co., and was presented by Earl Morrison, of the Budd Wheel Co.

After setting forth the advantages of welded-steel bodies and briefly describing the construction employed, the authors said that difficulty in obtaining from the mills sheets of the size and accuracy required led to the development of a method of flash-welding together sheets 120 in. long and of any desired width. The large sheets thus produced are treated just as though they were rolled in one piece.

Extremely accurate alignment, such as is required in flash-welding long seams, is secured by magnetic clamping which results in self-contained pressure. In addition to the welding of the open sheets, 2303 spot welds and 140 in. of flash welding are found in a sedan.

Chairman Lincoln followed the presentation of the paper with the statement that arc welding has been developed during the last two years to the point where joints are essentially equal in ductility to the parent metal. Arc welding is slower than resistance welding, such as was described in the paper, but the cost of the equipment required is lower. Peter W. Fassler, manager of the electric-welding division of the Fisher Body Corp., contributed further information as to the requirements for flash-welding long sheets, including the need of correct pressure on the weld to get suitable structure and upsetting of the metal.

Inventory Control Concerns Management

At the opening of the Wednesday afternoon session, George L. McCain welcomed the audience in behalf of the Detroit Section and introduced V. P. Rumely, factory superintendent of the Hudson Motor Car Co., who presided. C. B. Stiffler, of the Oakland Motor Car Co., presented the first paper of the session, on the subject of Inventory Control.

Providing ample stock to guard against the possibility of the interruption of production for lack of material was said to be the chief aim of inventory control in 1920. Recognition of the importance of turnover is one of several factors that have led to a study of minimum stocks. Each car division of the General Motors Corp. now works on the basis of a definite monthly forecast based on 10-day reports from dealers of stocks and of actual and estimated sales. This forecast, which covers the current and three forward months, estimates the number of cars to be sold by the dealers, delivered to the dealers, and manufactured.

Capital and Cost Savings

In place of large stock-rooms, a limited amount of space is assigned for stock near the point where processing begins. The plant is zoned, with an experienced man in charge of stock in each zone. He has little use for any record except a shortage report which shows what items need attention. The efficiency of handling has been improved until a supply for three days is normal now. Minimum banks of processed parts also are maintained. Capital employed in inventories and buildings to house them now is estimated to be 25 per cent of what it would be if no improvement had been made during the last decade, and the cost of moving material is only 20 per cent of the former cost. Charts presented with the paper showed the inventory investment and inventory turnover of the General Motors Corp. from 1920 to 1931.

Inventory control presents two sides, one to the car manufacturer and one to the supplier of parts and materials, pointed out J. E. Padgett, assistant general manager of the Spicer Mfg. Corp., who approved the plan presented in Mr. Stiffler's paper from the standpoint of the supplier. He called for cooperation between car makers and parts makers so that the latter will not be left holding the bag; they should not be required to carry big stocks or do stunts to satisfy unexpected and unreasonable demands on the part of the car manufacturer. He said that inventory control for minimum stocks should be carried only to the point of economical relationship.

Other contributions to the discussion

Meetings Calendar

National Meetings of the Society

Annual Dinner—Jan. 14, 1932
Pennsylvania Hotel, New York City

Annual Meeting—Jan. 25 to 29
Book-Cadillac Hotel, Detroit

November Section Meetings

Baltimore—Nov. 12

Emerson Hotel Ballroom; Dinner 6:30 P. M.

Production of International Trucks—By an engineer of the International Harvester Co.

Chicago—Nov. 3

Sherman Hotel; Dinner 6:30 P. M.; Entertainment

Automotive Steels—T. H. Wickenden, Metallurgical Engineer, International Nickel Co.

A Century of Progress—By a speaker from the 1933 World's Fair

Cleveland—Nov. 9

Hotel Statler Ballroom; Dinner 6:30 P. M.

New Developments in Protective Coatings—Robert J. Moore, Bakelite Corp.

Detroit—Nov. 9 (Body Activity)

Book-Cadillac Hotel; Dinner 6:30 P. M.

Some European Sources of Automotive Color Inspiration—Howard Ketcham, Director, Duco Color Advisory Service, E. I. duPont de Nemours & Co.

Wood in Automobile Bodies—William L. Hodge, Vice-President, The Mengel Co.

Steel in Bodies—Clifton Reeves, Vice-President, Mullins Mfg. Co.

Detroit—Nov. 24 (Student Activity)

General Motors Research Auditorium, 8:00 P. M.

Subject: Design; Speakers: A. P. Brush, on Engines; L. C. Hill, on Bodies; and a third speaker, on Chassis.

Indiana—Nov. 17

Hotel Severin, Indianapolis; Dinner 6:30 P. M.

Subject: Lubrication

Kansas City—Nov. 13

Highway Construction and Laws—T. H. Cutler, Chief Engineer, Missouri State Highway Commission

Motor-Truck Operators on Highway Transportation—C. E. Lange, President, Missouri Motors Distributing Corp.

Metropolitan—Nov. 19

A. W. A. Clubhouse, New York City; Dinner 6:30 P. M.

Milwaukee—Nov. 4

Milwaukee Athletic Club; Dinner 6.30 P. M.; Entertainment.

Northern California—Nov. 12

Stanford University.

Northwest—Nov. 6

New Washington Hotel, Seattle, Wash.

Transportation—Prof. E. O. Eastwood, Director of Aeronautics and Mechanical Engineering, University of Washington

Hedges Two-Way-Piston Engine—Harry Hedges, Inventor and Designer

Oregon—Nov. 6

Multnomah Hotel, Portland; Dinner 6:30 P. M.

Highways, Their Alignment, Illumination and Relation to Safety—Prof. Robert Glenn, Department of Civil Engineering, Oregon State College

Time Reaction and Its Relation to Vehicle Accidents—Prof. J. F. Brumbaugh, Department of Physiology, Oregon State College

Brakes, Their Relation to Safe Operation—Dr. F. C. Stanley, Chief Engineer, Raybestos-Manhattan, Inc.

Philadelphia—Nov. 12

Philadelphia Auto Trades Association; Dinner 6:30 P. M.

Highway Construction from Viewpoint of Licensing and Law-Enforcement Authorities—L. G. Hoffman, Commissioner of Motor Vehicles, State of New Jersey

Highway Construction from Viewpoint of Motor-Vehicle Operator—J. F. Winchester, Supervisor of Motor Equipment, Standard Oil Co., of N. J.

Pittsburgh—Nov. 5

Important Factors Affecting Engine Operation—Ralph Teetor, Vice-President, Perfect Circle Co.

Southern California—Nov. 6

Elks Club, Los Angeles; Dinner 6:30 P. M.

Commercial-Vehicle Work of the California Highway Patrol—A. J. Ford, Inspector of Commercial Vehicles, California Highway Patrol

Fleet Owners' Viewpoint on Brake Problem—P. H. Ducker

Power Application on Brakes—Ethelbert Favary, Consulting Engineer, Moreland Motor Truck Co.

St. Louis—Nov. 10

Coronado Hotel; Dinner 6:30 P. M.

Subject: Transmissions

Syracuse—Nov. 5

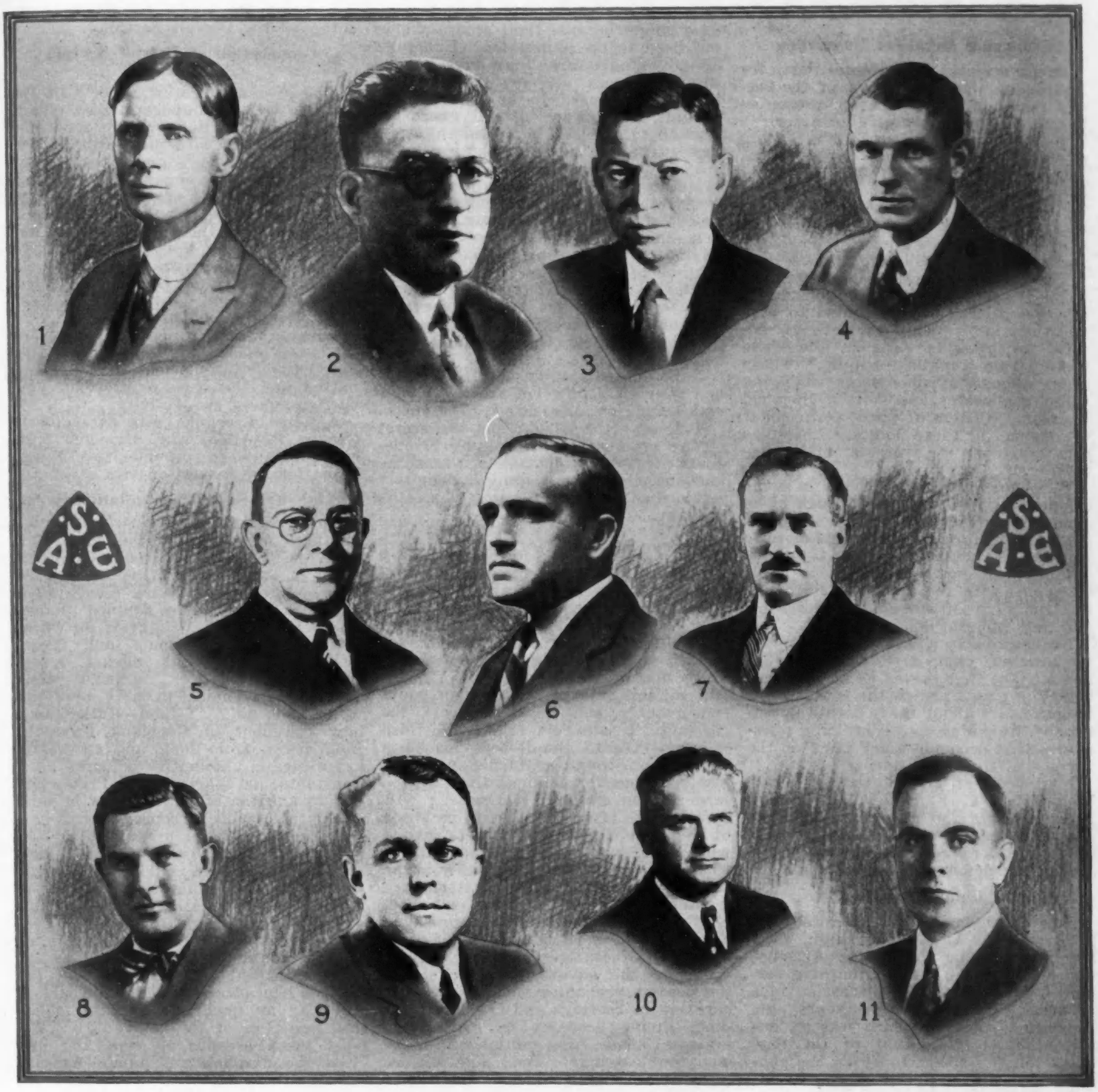
Drumlin's, Nottingham Road, Syracuse; Dinner 7:00 P. M.

Quality Control of Motor Fuels—A. L. Beall, Engineer, Vacuum Oil Co.

Fitting Fuel to Engine and Engine to Fuel—T. A. Boyd, General Motors Corp. Research Laboratories

Wichita—Nov. 12

Motion Pictures of Flights Throughout Mexico and the United States—Truman Wadlow



CHAIRMEN OF SESSIONS AND AUTHORS WHO PRESENTED PAPERS AT THE NATIONAL PRODUCTION MEETING

(1) J. C. Lincoln, of the Lincoln Electric Co., Chairman of First Session. (2) J. W. Meadowcroft, of the Edward G. Budd Mfg. Co., Co-Author with James J. Paugh of the Paper on Welding. (3) V. P. Rumely, of the Hudson Motor Car Co., Chairman of Second Session. (4) F. P. Spruance, of the American Chemical Paint Co., Who Gave the Paper on Cleaning and Preparing Sheet Metal for Enameling

(5) A. K. Brumbaugh, of the White Motor Co., and Vice-President of the S.A.E. Production Activity, Toastmaster at the Production Dinner. (6) Louis Ruthenburg, of Copeland Products, Inc., Who Made an Address on Constants and Variables in Production and Production Men. (7) Dr. Phillips Thomas, of the Westinghouse Electric & Mfg. Co., Who Demonstrated Electrons at Work and at Play

(8) W. H. Graves, of the Packard Motor Car Co., Chairman of Third Session. (9) J. H. Friedman, of the National Machinery Co., Who Presented the Paper on Hot Coining, or Machining by Pressure. (10) J. D. Dostal, of the Holley Permanent Molding Machine, Inc., Who Described the Economic Advantages of Molding with Permanent Machines. (11) George B. Allen, of Dodge Brothers, Who Provided Transportation for the Visit to the Holley Permanent Molding Machine Plant

were made by J. H. Moore, of Hudson; J. L. Juhl, of Murray Body; F. A. Upton, of Dodge; and Chairman Rumely.

Preparing Metal for Enameling

Preparation of Sheet-Metal Parts for Enameling was the subject of the second paper of the afternoon, presented by F. P. Spruance, of the American Chemical Paint Co. Four cleaning methods were described. Use of an oil solvent leaves harmful traces of oil because of its rapid evaporation. Burning off the oil at say 700 deg. fahr, leaves carbon. Vapor degreasing with hydrochloric acid is good if followed by a chemical rust inhibitor.

The most generally used method, which is spraying with a hot solution of alkaline salts, has been found to give unsatisfactory results sometimes because of alkaline salts in the rinse water from the city supply. These cause almost invisible spots when the water evaporates and start a chemical reaction. Blisters of water form under the enamel at these points, if moisture conditions are unfavorable, and cause rusting.

Phosphoric acid is the basis of some commercial rust inhibitors which overcome this difficulty. In one form it prevents the formation of drops of rinse water and neutralizes the alkalinity without causing a tendency to rust. Combined with an oil solvent, it is used in cleaning most automobile bodies for painting, Mr. Spruance tells us.

Bonderizing is a quick substitute for Parkerizing, which gives a fine crystalline surface that serves as an excellent bond for paint. Much the same result is obtained without the separate operation by a priming coat containing phosphates that decompose and react on the surface of the metal during baking.

Discussion of Mr. Spruance's paper brought out C. F. Dinley, of the Rex Products Co., who gave an illustrated description of a machine and process that have been recently developed for continuous cleaning of metal surfaces.

Hot Coining of Metals

How the industry has advanced was illustrated by A. K. Brumbaugh, Vice-President of the Production Activity, who opened the Thursday morning session, by comparing the discussion in a Production Meeting a few years ago, in which disposal of chips was an important item, with that of the day, which might be said to be on the subject of the prevention of chips. He introduced W. H. Graves, of Packard, to act as chairman.

Machining by pressure is the way J. H. Friedman, of the National Machinery Co., described the process of hot coining as applied to forgings, in the first paper of the session. Finish forging can be done on the Maxipres with the original heat remaining in the hammer forging, either before or after trimming, or the normalizing or annealing heat can be utilized. In either case, no additional operation is required for heating, and the forging is said not to be hot enough to scale during or after coining.

Advantages of this as an operation auxiliary to forging are that accuracy can be such that roughing and sometimes finishing operations can be dispensed with; no draft is necessary, because knockout devices can be used in the die; and the forging dies can be used longer because their accuracy does not need to be maintained. Examples of advantages are that press-forged connecting-rods are so uniform that they do not need to be matched for weight, and flywheel starter gears are pressed to size for bore and thickness so accurately that no machining is required except cutting the teeth.

Motion pictures showing the forging press at work were presented by Mr. Friedman, and an assortment of forgings finished by this process were exhibited in the meeting room. The discussion of the paper elicited the information that tungsten steel can be used for coining-dies, because they are not subject to shock. No warpage occurs in the parts after coining, either hot or cold.

J. E. Padgett remarked, "It is weird and wonderful how hot steel will flow under sufficient pressure." The material flows within itself, and the secret of the process of cold coining is adequate pressure without distortion of the machine. Semi-hot coining is definitely established, and cold forming of steel is in sight.

Permanent Molds for Casting Iron

Casting iron in permanent molds is the process described in the second paper of the session by J. L. Dostal, manager of Holley Permanent Mold Machine, Inc. Standard 12-head semi-automatic molding-machines are used generally for producing castings in quantity by this process. One man pours continuously and another ejects the castings. If cores are required, a third man sets them. Single-head machines are used for small quantities, and special machines for castings that are too large for the standard machines.

Molds are made from the same grade of iron that is poured into them, coated with a refractory facing and further with smoke applied automatically in the molding-machine. Master patterns are metal faced or made from hardwood. No finish is required in the impression, but the mold is normalized after casting and its faces are machined.

Among the advantages claimed for the process are uniformity in size and hardness of castings and freedom from sand, giving economy in machining; saving of space, time and labor in making the castings; and high-tensile, transverse, impact and compression strength in the product, with uniformly close grain and freedom from shrinkage. The casting and annealing operations can be controlled to give almost any desired degree of hardness.

No shrinkage occurs in die-castings, according to Mr. Dostal, because of the slow filling of the mold, usually from the bottom up, and the use of small gates. The discussion also brought out the information that every casting is annealed to give uniformity for processing and that die-casting has not yet been adapted commercially to malleable iron. Castings with steel inserts can be made without difficulty, and the process can be adapted to large castings such as whole cylinder-blocks.

Thursday afternoon was occupied by an inspection trip to the Holley plant, where die-casting machines were seen in operation. The meeting closed with the usual Production Banquet, sponsored by the Detroit Section.

Cooperation of Detroit Section Appreciated

One of the brightest aspects of the meeting was the important part played by the local Section, which cooperated very effectively with the National Production Activity and contributed largely to the success of the meeting. Vice-President Brumbaugh, who acted as master of ceremonies at the banquet, expressed the appreciation of the National Activity for this cooperation and mentioned, among those who assisted, Alex Taub, George B. Allen, W. T. Fishleigh, George L. McCain, V. P. Rumely and E. B. Reeser. Mr. Brumbaugh also recognized the work of Joseph Geschelin, Chairman of the Production Activity Meetings Committee, and the score or more of production men of the Activity.

A vote of thanks was extended to George B. Allen, who arranged with his company to provide two Fargo buses for the inspection visit.

Brumbaugh Supervises Inflation Event

Vice-President A. K. Brumbaugh skilfully maneuvering the big "Prepare-for-Prosperity" Production Banquet . . . 250 optimists present . . . Our V. P. deplores management's tearing-down operations of trained production personnel . . . Suggests we watch the cost of replacement and reconditioning these units during reconstruction period . . . Believes wiser and more economical to carry men than to let them go . . . Louis Ruthenburg, now president of Copeland Products, Inc., draws from long and successful experience in automotive industry . . . Constants and Variables in Production and Production Men . . . Says production is not equal to replacement . . . Now is the time to prepare for prosperity . . . In years past, anything that could be made could be sold; now anything that can be sold can be made . . . Changing of the product will be the price of survival . . . Producers must welcome quick changes . . . Manufacturing equipment must be kept adaptable and flexible . . . Industrial education, from the bottom up, will play an important part in industrial activities of the future . . . We must teach breadth of view and improve the economic and human aspects of industrial system . . . Prosperity is measured by wealth in motion . . . Study the Gerard Swope plan for industrial stabilization . . . As industry becomes more complex, our individual viewpoints must become more comprehensive . . . Prepare for Prosperity! advises Louis Ruthenburg . . . Dr. Phillips Thomas, of Westinghouse, sells 130 thousand million million electrons for five cents . . . Then entices a few billion of these electrical fleas to blow out the lights; shoot the apple from Tell, Junior's, head; start the wind blowing; put out fires . . . Wonderful . . . Remarkable . . . Astonishing . . . New tools for industry demonstrated in popular fashion . . . Dr. Thomas knows his electrons . . . That's all there is . . . There isn't any more of the Production Banquet.

Abstracts of National Transportation Meeting Papers

Some Problems of the Transportation Executive

Several major problems of the man who has charge of a fleet of automotive vehicles are pointed out by T. L. Preble, of the S P A Truck Corp., who states that they deserve closer scrutiny and more intensive study than have been accorded to them. Solution of them is a matter of evolution, which implies a long time, and continued discussion of them by the Society is imperative. The problems are not only those of the transportation executive but are those of the entire industry.

Centralized control of a company's equipment is discussed, its advantages being enumerated, the ideal organization and procedure outlined, the difficulties to be anticipated listed and a procedure for installing such a system proposed. The author recognizes that where the automotive activities of a gigantic company are spread over a wide territory, an ideal system of centralized control is very difficult of realization.

Consideration is given in the second part of the paper to the relationships between the transportation executive and the motor-vehicle manufacturer. These relations are those of buyer and seller, yet a peculiar need of this industry, points out the author, is that buying and selling be conducted on a high professional plane and in a spirit of tolerance born of intelligent appreciation of the other man's problem. The transportation industry demands salesmen who not only know specifications and prices but who have pleasing personality and a superior knowledge of highway transportation and the capabilities of equipment to serve specific purposes. The faults up to the present have too frequently been that salesmen have not been sufficiently informed and have deliberately misrepresented their vehicles, and the buyers have often failed to fully and accurately state their transportation needs. The manufacturer has been as much to blame as have his salesmen. Mr. Preble believes that the transportation executive can do much to improve the quality of salesmen by expressing his views forcefully to the higher executives of the manufacturing company as well as to the salesman.

Selection of the right unit for a specific service depends upon a clear and specific understanding between buyer and seller of all the facts of the case and implies technical ability on the part of both. Therefore a questionnaire form is proposed, with the recommendation that it be approved by the Society and its use by transportation executives and manufacturers be urged. If properly filled in, this form will give all essential data from which ability factor, load distribution, suitable gear ratios and other engineering calculations can be made.

Mr. Preble also suggests the desirability of a super-committee of representatives of trade associations, sponsored by the Society, for the purpose of discussing important problems that are common to the operator and the manufacturer, out of which discussion the manufacturer would gain guidance in his design and manufacturing problems. Eventually the need would become apparent for instituting a basic system of standardized major units from which could be assembled any combination within reason to produce a vehicle to suit the customers' requirements. Instead of a "line" of "models," this system would result in greater flexibility and minimize the problems of inventory and manufacture.

The National Transportation Meeting of the Society, held in the City of Washington Oct. 27 to 29, came too late in the month to permit of printing a report of it in this issue of the S.A.E. JOURNAL without delaying the mailing of the issue too much. For the information of those who were unable to attend the meeting, summaries of the papers prepared for the meeting are printed herewith.

The full news reports of the sessions, the discussion on the papers, portraits of the chairmen and authors, the inspection trip, the visit to the White House and the Transportation Dinner will be published in the Transportation Number of THE JOURNAL for December.

In the third part of the paper the relations between the transportation executive and his superior are discussed, the qualifications the fleet superintendent should have are enumerated and the responsibility of the higher company executive for the efficient and economical operation of the fleet is set forth. A plea is made for such executives to give sufficient time to become acquainted with the superintendent's problems and to give him the necessary authority, recognition and compensation that are demanded if real transportation economies are to accrue.

Rail and Highway Transport Coordination

In his paper on this subject, Samuel O. Dunn, editor of *The Railway Age*, begins with the premise that the sole objective in seeking a solution of our transportation problem should be the promotion of the welfare of the Nation. He asserts that the only solution of it that will promote the National welfare will be the effecting of economically sound coordination of all our different means of transportation. Economically sound coordination will exist when each means of transportation renders the service for which it is best fitted. Each is best fitted to render that service which it can render at the lowest cost, allowing for differences in convenience and other factors determining the value of the service to those to whom it is rendered.

To ascertain what traffic should be handled by each class of carriers, they must be given "equality of opportunity" by avoiding or abolishing governmental discrimination between them. Government discriminates and denies equality of opportunity if it pays part of the cost essential to the rendering of the service of one class of carriers and does not pay part of such costs of another class of carriers, or applies regulation to one class and does not apply comparable regulation to another class.

Because of the actual practice of the kinds of governmental discrimination mentioned, Mr. Dunn states, the railroads are being depressed and the expansion of other means of transportation is being artificially stimulated, with numerous economic results that are highly inimical to the welfare of the public. Therefore prevailing governmental policies should be changed so as to force those who render any kind of transportation service to pay all the costs of rendering it out of their own earnings and to subject all classes of carriers to comparable regulation of their service and rates.

Under competition on equal terms, each class of carriers will then soon be left supreme in its own natural economic field and excluded from other fields. The results will be that the railroads will again become almost the sole long-haul inland carriers of the Country, the trucks will retain and increase their terminal and short-haul business, and coordinated rail-truck service will carry a large and increasing amount of traffic from the door of the shipper to the door of the consignee.

Truck Legislative Activities in 1931

Pierre Schon, of the General Motors Truck Co., deals with legislative activities in 1931 relating to motor-trucks and the effects on design and operation of commercial vehicles. Problems of the vehicle manufacturers and the designing engineers, the truck operators and shippers threaten to become more complicated if the tendency to restrict commercial vehicles to smaller sizes and weights by State legislation is continued. The author considers what can be done by the Society and its individual members to safeguard the interests of the motor-truck and motorcoach industry, not only as regards the

future design of vehicles, but also the investments of operators, which aggregate millions of dollars in present equipment that may be obsoleted at any time through unwise State legislation.

Commercial Application of Diesel Engines in Motor-Vehicles

This paper by George A. Green, of the General Motors Truck Corp., covers comparative dynamometer and road tests of heavy-duty Diesel and gasoline engines having approximately similar piston displacements. Pictures and brief descriptions of both engines, including weight data and power output per unit of displacement, are given. The dynamometer-test data include comparative horsepower, torque and fuel consumption. The road-test data cover the comparative performance in general, including maximum speed, hill climbing, acceleration and fuel economy. The same vehicle and load were used for all road tests, the difference between the vehicles consisting only in the engines and their attaching parts. An analysis is made to show what the author believes to be the economic possibilities of the Diesel engine as applied to heavy-duty-vehicle operation and the practical advantages and disadvantages. Some brief comments concerning Diesel-engine fuel problems are also given.

Chassis Lubrication

A. J. Scaife, of the White Motor Co., based his paper entitled Chassis Lubrication on about 18 replies received to a letter asking for information and suggestions on the subject. These came from representatives of six motor-vehicle-fleet operators, five vehicle manufacturers, four lubricant manufacturers, two trade journals and one consulting engineer.

After listing the information and suggestions, the author asserts that the letters clearly show that the present chassis-lubrication practice is unsatisfactory. He asks, What is the problem? What are we trying to lubricate that takes 20 kinds of lubricant, and why? He lists 15 principal units requiring lubrication and the kinds of lubricants used for each. Noting that two kinds of bearings—plain and antifriction—are used in all of these units, he asks why half a dozen different kinds and grades of grease should be used for plain bearings and asserts that we have been trying to correct faulty design by using different kinds of lubricants; that is, have been working on the effect instead of the cause.

Mr. Scaife believes that the necessity for a multiplicity of so-called special greases can be eliminated and the chassis lubricated with not more than three kinds of oil or grease if the problem is studied with reference to design, giving consideration to pressure, individual-magazine and central-station or so-called one-shot lubrication, at the same time considering the required clearance for the working parts under each system. He recommends that the Society undertake this study.

The situation is very similar, the author points out, to that which existed several years ago with reference to gasoline, of which numerous kinds and qualities were marketed for motor fuel. Various brands of gasoline are marketed now but the requirements can be confined to two grades on which almost all modern engines will operate with fairly uniform and satisfactory results. If the same amount of engineering thought is concentrated on the problem of selecting a lubricant for the chassis as was devoted to the fuel problem, and to suiting the engine, transmission and axle to it, a standard can be developed that will remedy the present chaotic condition.

Motorcoach Chassis and Body Relationship

The motorcoach body today has the principal influence on the design of the motorcoach chassis, according to George H. Scragg, of Mack Trucks, Inc., writing on the subject, Motorcoach-Chassis Relationship to the Motorcoach Body. Since completely harmonious motorcoach design requires compromises between body design and chassis design, he states, each must be to some extent subservient to the other.

This change from former practice was inspired by the public's appreciation of comfort to such an extent that it demanded greater refinement of the motorcoach body. Hence, the builders vied with one another in providing luxurious appointments, comfortable seats, generous aisle space, convenient doors, ample headroom, and thoughtful positioning of windows and the minimizing of wheelhouse obtrusion. Rider appeal became as essential as durability and performance, comfort and attractive appearance vital for increase of traffic volume, and the chassis became subject to the dictates of body requirements.

Nevertheless the exactions for performance, economy and reliability have become more severe under the pressure of intensified competition; yet the demand is that the means of attaining them shall be dictated by the demands of body layout and mounting.

For operating effectiveness the chassis must have a large power-to-weight ratio, for economy it must be as light as possible, and for reliability and ease of maintenance it must be simple and compact. On the other hand, the requirements of roominess, capacity, comfort and convenience of the body have steadily increased the necessary weight, size and complication of the chassis, while performance requirements of ever-increasing severity have required continued increase in engine power, brake effectiveness and steering ability. As chassis, engines, frames and tires increased in size to keep up with these developments, the tendency has been to increase the difficulties with which the motorcoach-body designers have had to contend.

After elaborating on the foregoing statements, outlining the details of the rapid development of both body and chassis design and pointing out the difficulties which designers must surmount, Mr. Scragg concludes that basic motorcoach-design characteristics today are being conceived as a unit with the requirements of the body. To what extent this line of progress will modify conventional motorcoach outlines and details of construction is indicated by the work already accomplished in chassis of the hoodless mass-transportation type. Even on the more conventional types, greater compactness is being secured by straddle-type dashes, semi-forward-type controls and engines specially designed for longitudinal compactness.

What the Bureau of Standards Is Doing for Business

In the paper by Dr. George K. Burgess, director of the Bureau of Standards, are given brief outlines of the functions of the Bureau; the establishment by the Bureau of the fundamental measures of length, weight, volume and time upon which all other measures are based; the bearing of the accuracy of such measures upon business transactions; scientific and industrial research conducted at the Bureau; the research associate plan inaugurated to enable industrial organizations to conduct at the Bureau specific researches on important problems affecting their specialties; researches in the automotive field and their economic significance; simplified practice recommendations and commercial standards formulated under the auspices of the Bureau by industries for their own use; certification and labeling plans for facilitating the utilization of Federal specifications and commercial standards, and the marketing of quality products.

Committees Plan Two Big Events

Annual Dinner to Make January 14 a Memorable Date— Annual Meeting Set for Week of January 25

GENERAL DEPRESSION will not be among the guests at the 1932 Annual Dinner. For one thing, he will not be invited; there will be no place for him. If he should be so bold as to crash the gate and come uninvited, he would receive too cold a welcome to make it possible for him to stay. As a matter of fact, it is hoped that he will have been banished from our midst before that time and will have taken his departure for that distant country known as the land of the remote past. In any event, he will have no part in the program of the 1932 Annual Dinner, which is to be held at the Hotel Pennsylvania, New York City, on the evening of Jan. 14, 1932, the Thursday of the New York Automobile Show Week.

The Dinner Committee, composed of Chairman Adolf Gelpke and Frederick K. Glynn, is busy making the preliminary arrangements for the program, which promises to be one of unusual interest to all S.A.E. members. Announcements will be made at a later date regarding the speaker and the various entertainment features of the Dinner. Members and guests who have attended the Annual Dinners of the Society in the past will find the 1932 event measuring up in every way to the high standard set by its predecessors, and those who have not yet known the delights of an S.A.E. Annual Dinner will have an opportunity to enjoy what gives every indication of being one of the very best ever staged.

Varied Annual Meeting Program

The week of Jan. 25 will find members of the Society thronging the ballroom floor of the Book-Cadillac Hotel in Detroit, where the Annual Meeting will be in progress. Sessions being formulated by the Professional Activities, the Research Committee and the Meetings Committee will appeal to the varied interests of those who compose the membership of the Society.

Attention will be devoted to different phases of aircraft, Diesel engines, passenger-cars, passenger-car bodies, motor-trucks, motorcoaches, production, transportation and research. At the request of the Passenger-Car Activity, three sessions were allotted by the Meetings Committee for the presentation of topics of interest to passenger-car engineers. At these sessions papers will be presented on problems concerning bearings, front-wheel alignment, riding-qualities and a new type of engine mounting, namely, that of the Plymouth car. Vice-President E. S. Marks, Chairman Walter C. Keys of the Passenger-Car Meetings Committee, and all who have helped in arranging these three sessions are to be congratulated upon a splendid job, thoughtfully planned and expeditiously handled.

Because of their community of interest, the Transportation and Maintenance and the Motorcoach and Motor-Truck Activities have requested that their respective sessions be held on the same day, one in the morning and the other in the afternoon. Likewise, the Passenger-Car-Body Activity, in requesting that its papers be scheduled for an afternoon session, expressed the hope that the session containing the paper on the Plymouth engine mounting would be held in the evening immediately following the Body Session, as it was believed that the same engineers would be interested in both sessions and that the juxtaposition of these two sessions would be distinctly advantageous. Chairman N. G. Shidle and other members of the Meetings Committee, in laying out the program, are considering these suggestions.

Timely discussions of Diesel-engine problems will be sponsored by the Diesel-Engine Activity, and a production session that is expected to make a broad appeal is being planned by the Production Activity. As is customary, the Research Committee will arrange for a session at which will be revealed further information that has been brought to light as a result of the important and significant investigations of the cooperative fuel research which is being carried on at the Bureau of Standards under the auspices of the National Automobile Chamber of Commerce, the American Petroleum Institute and the Society.

An aircraft session has been planned that will be of intense interest not only to aircraft men but to everyone attending the meeting, both on account of the topic itself and because of the authority of the man who has agreed to present the material.

As the Annual Meeting is general in character, and not devoted to any specific aspect of the Society's work, every effort has been made, in selecting topics and speakers, to have the program present, so far as possible, a cross section of Society interest and activity. Meetings Committee members and others who have helped in arranging the various sessions believe that every member, whatever his own special line of work, will find something in the Annual Meeting program of particular usefulness to himself; and that the broader the professional outlook of a member the more he will find of interest in the sessions that have been outlined and developed for his information and profit.

The number of papers to be presented at each session has been definitely limited in order that adequate time may be available for discussion. The authors of the papers will be glad to answer questions at the sessions, and members are urged to take part in the discussion of as many of the papers as are of special interest to them.

More detailed announcements concerning the various sessions to be held and the papers to be presented will be made in subsequent issues of the S.A.E. JOURNAL and in Meetings Bulletins.

Strict Time Schedule

Sessions of the Annual Meeting will begin and end at specified times. The Meetings Committee and the various Professional Activities Committees are unanimously insistent upon this point, and every effort will be made to assure the prompt starting and closing of sessions. To secure an equitable division of time among the speakers and discussers at a session, each author will be given a definite time allotment, and a definite amount of time will be allowed for the discussion of each paper. These time allowances will be made known to the authors and the respective session chairmen, who will be urged to adhere strictly to the time schedule given them. The Meetings Committee and the Professional Activities Committees bespeak the cooperation of all who attend the meeting, as the audience can in every case help greatly by assembling promptly in the meeting room at the appointed hour.

Even at this early date, nearly three months prior to the meeting, it is apparent that all the elements of a successful meeting are being procured by the committees in charge of the undertaking. Timely topics have been chosen, interesting and authoritative speakers have been selected, capable and judicious chairmen will preside at each session, and the arrangements for the various details of the meeting are being handled under the supervision of committees that are alert and know their jobs. The Annual Meeting, therefore, undoubtedly will be an event that the progressive member will most strongly desire to attend, an occasion characterized by the imparting and receiving of valuable information, the holding of many formal and informal discussions and conferences, the strengthening of both professional acquaintanceships and personal friendships and the enjoyment of worthwhile and stimulating contacts.

Chronicle and Comment

Thomas Alva Edison IN THE passing of Thomas Alva Edison our Society has lost a most distinguished member and the world is bereft of a personality whose services to mankind are beyond measure.

President Hoover, in recommending a "dark minute" to honor the memory of the great man, is quoted as saying, "The suggestion has been made that the electrical current of generating plants should be turned off at these hours, but on inquiry I find (and this is confirmed by Thomas Edison, Jr.) that this would constitute a great peril of life throughout the Country because of the many services dependent upon electrical power in protection from fire, the operation of water supply, sanitation, elevators, operations in hospitals and the vast number of activities which, if halted even for an instant, would result in death somewhere in the country. It is not, therefore, advisable.

"This demonstration of the dependence of the Country upon electrical current for its life and health is in itself a monument to Mr. Edison's genius."

Production and Prosperity LOUIS RUTHENBURG sounded the keynote of the National Production Meeting, held in Detroit, Oct. 7 and 8, when he advised a large gathering of production men to "prepare for prosperity." Mr. Ruthenburg's address, delivered at the banquet, suggested numerous ideas in keeping with the text, "As industry becomes more complex, our individual viewpoints must become more comprehensive."

Detroit Section Cooperates ONE OF the biggest elements contributing to the success of the National Production Meeting was the excellent cooperation of the Detroit Section. Under the leadership of Alex Taub, Chairman of the Section, our local members figured very effectively in almost every phase of the undertaking.

Events that are sponsored primarily by our National Activities always gain materially from this sort of joint responsibility and the local Sections derive a very real benefit from their association with projects of National scope.

Council Considers Finances FINANCIAL AFFAIRS of the Society were of principal interest to the members of our Council who met in the City of Washington on Oct. 30. Considerable gratification was expressed in the report of the Finance Committee, which showed the financial results of our operations during the fiscal year ending Sept. 30 to be much more favorable than was anticipated; this in spite of an appreciably reduced income from JOURNAL advertising. A budget for the 1931-1932 fiscal year was adopted.

The Society is indeed fortunate to have a Council and Finance Committee whose members are as well versed in the sound principles of conservative business conduct as they are learned in matters of engineering.

S.A.E. and International Standardization IT IS interesting to note in connection with the progress in standardization since the World War that a great movement in this direction has developed in virtually all American industries and in nearly all foreign countries supporting manufacturing industries. National standardizing agencies have been established in almost all of them and more recently an International Standards Association was organized by a majority of these countries. In the United States the American Standards Association is the recognized agency for general international standardization activities. In the course of these developments, many of the Standards of the S.A.E. have been adopted by many other countries with little modification except possibly conversion to metric measurements.

The international scope of the Society's membership has probably been instrumental to some extent in the introduction of S.A.E. specifications abroad but probably the main reason is that close relations have been maintained between many of the foreign national bodies and the Society in the standardization work. Among the national bodies with which the Society maintains direct and frequent contacts are the Canadian Engineering Standards Association; British Engineering Standards Association, the Institution of Automobile Engineers and the Society of Motor Manufacturers and Traders, Ltd., England; the Bureau de Normalisation de l'Automobile in France; Normenausschuss der Deutschen Industrie and Reichsverband der Automobilindustrie E. V. in Germany; Comitato Generale per l'Unificazione Nell' Industria Meccanica in Italy; Svenska Industriens Standardiseringskommission in Sweden; and Schweizerische Normalien Vereinigung in Switzerland.

Culmination of a Three-Year Program SEPT. 14, 1931, was a red-letter day in the history of progress toward a solution of the detonation problem. At its meeting on that day, the Cooperative Fuel-Research Steering Committee formally approved the C.F.R. test unit[1] for the determination of the knocking characteristics of motor fuels in terms of octane numbers which has been developed through the efforts of the Subcommittee on Methods of Measuring Detonation as a result of a three-year program of cooperative research.

In the course of this undertaking, a Tentative Recommended Procedure for Conducting Antiknock Tests, using the specified equipment, has been formulated and approved[2] and a scale for expressing antiknock results in terms of octane numbers agreed upon by the Committee and adopted by the Society as Recommended Practice.[3]

Transportation Issue in December ALTHOUGH THIS issue of the S.A.E. JOURNAL carries abstracts of papers that were presented at the National Transportation Meeting, held in the City of Washington, Oct. 27 to 29, the December JOURNAL will be the Transportation number. In it will be found news accounts of the various sessions and many interesting items connected with the meeting that could not be published in this November issue.

[1] See the S.A.E. JOURNAL, June, 1931, p. 637.
[2] See the S.A.E. JOURNAL, August, 1931, p. 164.
[3] See S.A.E. HANDBOOK, p. 607.

The Tear-Drop Car

Semi-Annual Meeting Paper

By Walter T. Fishleigh[1]

DRAWING an aerodynamic parallel between a conventional 1931 sedan and a milk-wagon, the author discusses improvements which can be accomplished by streamlining. Surrounding the required automobile seating space with a streamline body resembling fast fish or modern aircraft, an automobile is developed which has remarkable possibilities in matters of decreased wind resistance, fuel economy, riding comfort and clear vision, in addition to striking beauty and grace. Results of wind-tunnel tests upon models of this "tear-drop" design and of a conventional sedan are included. Quotations from various authorities are presented commending new styles and new beauty when they incorporate functional improvement. A complete mechanical design, including engine mounted at the rear, is shown, but mechanical details are not emphasized because of the numerous variations that are possible.

Discussers present evidence of economy from streamlining and raise questions as to stability and road resistance. Relative structural advantages and probable riding qualities are discussed, and a plea is made for more individuality in cars. Constants determined from further wind-tunnel tests are reported.

IF WE STARTED out today to design a fast automobile and were not handicapped by precedent and fashion our new automobile would not look, act or be mechanically arranged like present automobiles. Every automotive engineer who has kept abreast of developments along automotive lines—automobile, aeronautic, submarine, racing—will concur in this statement, radical as it may seem.

When the automobile was originally designed, 30 or more years ago, it was a slow-moving vehicle, the next step forward from the horse and wagon. At that time, when the style and general arrangement of the car were established, there may have been reason for simulating in appearance and general arrangement the horse-drawn runabout or milk-wagon. Furthermore, reliability and speed were then conspicuous by their absence, and any consideration of aerodynamic design, which is so tremendously important to high-speed travel through air, would have been quite far-fetched, not to say ridiculous.

In the beginning, the so-called horseless carriage was simply a carriage without a horse; and engineers religiously attempted to preserve this idea by appropriating the conventional design of horse-drawn runabout or victoria, simply omitting the horse, the shafts, and the harness and hiding the engine under the seat or in the deck behind the seat. This style and arrangement did not last long, for two reasons: first, the public began to talk about and demand more horsepower and wanted to see evidence of it; second, there simply was not room for increased power under the seat of the conventional buggy. Thus was painfully conceived the arrangement of the engine in front and the passenger compartment behind, a style and a mechanical arrangement which have presisted until now.

Now, when the automobile is no longer the uncertain, temperamental, slow-speed, short-distance car of 25 or 30 years ago, one of its outstanding requirements and virtues is speed. With speed comes increased air-resistance in more than direct proportion; and, with increased air-resistance, considerations of scientific streamlining become of prime importance in relation to speed, horsepower required and fuel economy. In view of these changed conditions, we may well wonder at two facts:

(1) That the general outline of the typical closed car has remained practically the same for almost 20 years.

(2) That this general outline resembles so strikingly the horse-drawn milk-wagon of 1931 or of 1913, as shown in Fig. 1.

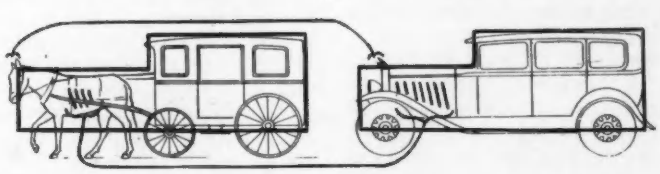


FIG. 1—THE CONVENTIONAL SEDAN FOLLOWS THE MILK-WAGON

The more we consider the two general outlines, the more we wonder at such a coincidence; and, since the two outlines represent perhaps the two widest extremes in speed in 1931 transportation, we wonder whether there may not be something wrong about one or the other. The typical 1931 sedan is like the milk-wagon, not only in having its horsepower out in front of a vertical-ended, wind-disturbing, box-shaped body; it even simulates it in the matter of ears at the front and louvers on the side of the horsepower compartment.

Considerations like the foregoing led the writer and some of his assistants several years ago to undertake a synthetic development of a fast automobile on the assumption that all of its various features could be given proper relative scientific weight, with no handicaps of precedent or fashion. Minutely accurate quarter-size models were built later, and check tests were run in an aerodynamic wind-tunnel.

Now that racing speeds have reached 245 m.p.h. and four-lane high-speed cross-country highways are being developed everywhere, no one knows how soon 100

[1] M.S.A.E.—Consulting engineer, Detroit.

m.p.h. will be a common cross-country touring speed with greater safety than a speed of 50 m.p.h. on present highways. Both engineers and the general public to-day realize that shapes like the body of a trout or a bird or the elongated contour of the falling rain-drop have remarkable advantages as to air resistance in high-speed travel through the air.

We are familiar with and have learned to like the beauty and symmetry of streamlined bodies like those of the airplane and the dirigible; but few people, even engineers, realize that a correctly shaped body will travel through the air at 30 to 60 m.p.h. with only one-third the air resistance of an incorrectly shaped body of the same volume. For instance, a plain cylinder having a length about $1\frac{1}{2}$ times its diameter has four times as much air resistance at any speed as the same cylinder with correctly streamlined ends added.

The foregoing means that an automobile body designed in the form which we know to be best would travel through the air with one-third the air resistance of present closed bodies. Since air resistance is the greatest part of the total resistance of an automobile at touring speeds, a properly shaped automobile can be made to travel from 2 to $2\frac{1}{2}$ times as far per gallon of fuel as a conventional car, the proportion depending upon the speed. In other words, the streamlined car would give 20 to 50 miles per gallon, instead of 10 to 25 miles as at present. A modern automobile—with its many exterior air-disturbing appurtenances, such as fenders, lamps, bumpers, axles, wheels and extra tires—offers about five times as much air resistance or drag at any speed as would a simple full-streamlined airplane body of the same passenger-carrying volume.

Basis of Streamline Body Form

With these startling but well-established observations as a background, we assumed the number of passengers to be accommodated in an automobile and the desirable dimensions for the seats, steering-wheel, roof and floor, as indicated by the dimension lines in Fig. 2. We proceeded to throw about the points thus established a full-streamline enclosure, resembling the form of a graceful fish, a soaring bird or a fast airplane, and then to study the resulting structure as to adaptability to doors, axles, wheels and engine.

The British Admiralty has conducted exhaustive tests upon airship models based upon the forms of the fastest and most efficient fish which evolution has produced. Some of these fish are shown in Fig. 3, and Fig. 4 illustrates the streamline forms which the Admiralty de-

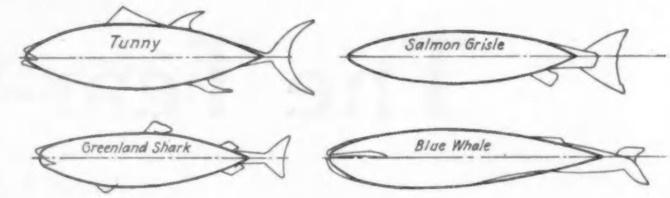


FIG. 3—OUTLINES OF HIGH-SPEED FISH

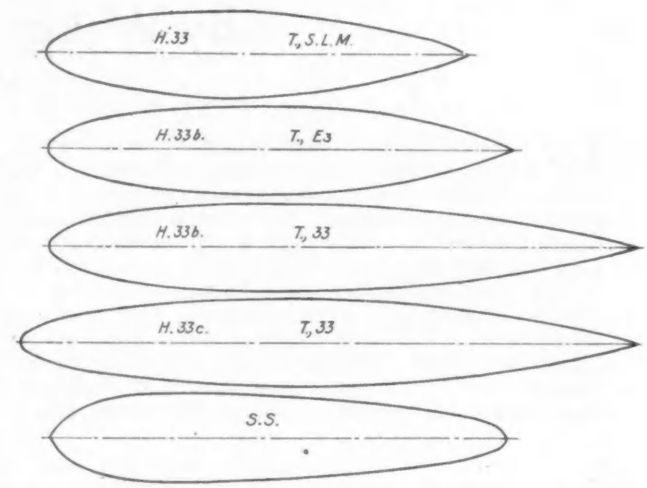


FIG. 4—AIRSHIP FORMS DEVELOPED BY BRITISH ADMIRALTY

rived from its work. It is noticeable that the second form from the top, marked T.,E3, showed an aerodynamic efficiency approximately as high as that of any of the proportionally longer designs illustrated.

This form, virtually that of the Greenland shark or blue whale, was adopted as a model for the streamline enclosure shown in Fig. 2. Then it was discovered that the streamline body not only was adapted to fast and economical travel through the air but it had unexpected advantages in connection with other features and units of the car, as follows:

(1) A body of this form is adaptable to unit construction, simulating the trussed structure and strength of a bridge, eliminating the need for the conventional chassis frame.

(2) With suitable streamlining and the bottom of the body modified to be more nearly parallel to the road surface, there was ample room behind the rear seats for the engine, eliminating its usual noise, vibration, heat and odors.

(3) In front of the front seat is ample room for the steering-gear and storage space comparable with that in the deck of the ordinary roadster.

(4) The engine, transmission, rear axle and rear springs can be incorporated in one unit which is assembled directly to the body frame on the final assembly line.

(5) The front springs, front axle and steering mechanism can be incorporated in another unit, which also is assembled to the body on the final assembly line.

(6) The seats can be placed between the axles and may be as low as desired, because of the absence of the propeller-shaft.

(7) The streamlining at the front can be modified to obtain clear vision without materially sacrificing aerodynamic efficiency; it is the maintenance of approximately correct streamline form at the rear that is of great importance.

(8) Fenders, running-boards and outside head-lamps can be streamlined or their wind resistance can be eliminated by incorporating them in the main structure of the body.

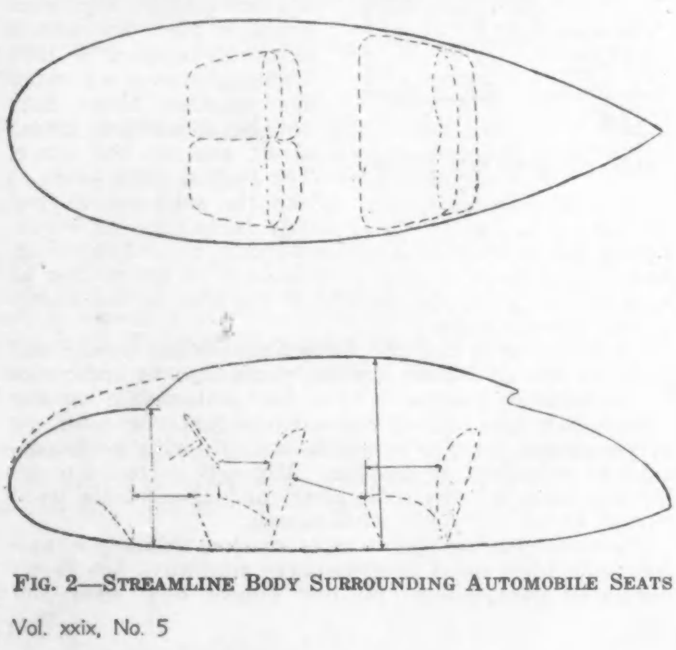


FIG. 2—STREAMLINE BODY SURROUNDING AUTOMOBILE SEATS

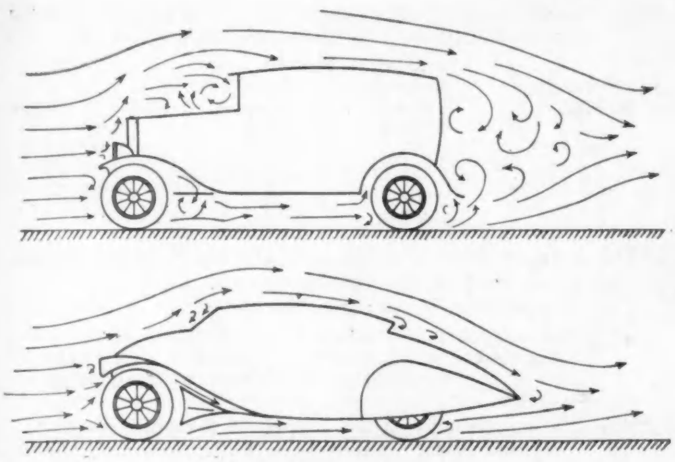


FIG. 5—DIAGRAM ILLUSTRATING AIR-FLOW AROUND CONVENTIONAL AND TEAR-DROP CARS

(9) The general outline—including the main streamlined form, windows, moldings and color scheme—are adaptable to unlimited variation.

Beautiful in line and symmetry and functionally correct, the gracefulness of such a design, compared with the shapes of present automobiles, is readily apparent. The appearance of such a form is at first strange, even perhaps startling; but, since there is nothing harsh or incongruous about the design and since we know that there is fundamental reason and logic back of it all, it grows upon us and we learn to like it. Even at first glance it is not difficult to say that, if it were not conspicuous because of its difference from current styles, we might prefer it to the conventional closed car of similar capacity.

Improvements Available in Streamline Car

Although a completely symmetrical streamline form would not be possible or aerodynamically desirable for a car running close above a road-bed, our theory was that a streamlined automobile could be designed which would possess striking beauty and attractiveness of line and contour and at the same time show remarkable decrease in wind resistance and therefore remarkable improvement in fuel consumption. Our theory went further; for we also believed that—by rearrangement and reconstruction of the chassis units, notably by mounting the engine at the rear and by swinging the seats low between the axles—great improvement could be provided in visibility and in general riding comfort.

Fig. 5 illustrates, for comparison, the theoretical air-flow past a conventional five-passenger sedan and a streamlined rear-engined tear-drop car of the same passenger capacity. The interferences and swirling indicated at both front and rear of the ordinary car spell frontal resistance and rear-end drag which in the tear-drop car can be largely converted into skin friction of a tremendously lower order of resistance.

Figs. 6 and 7, respectively, show our test models of a conventional production sedan and a full-streamlined rear-engined tear-drop car. The models were constructed one-quarter size, complete and exact in every detail, and were painted in attractive color combinations.

These models were displayed and their advantages were explained to each of 38 different people at two or more different times. This number included chassis engineers, body designers, airplane experts, salesmen, general executives and the ordinary automobile users. All except four expressed approval, ranging from simple statements that they "thought such a design would be successful," to enthusiastic statements that "the design is absolutely right and the public would fall for it immediately."

Of the dissenting four, two thought the design too radical to take at one step, one was non-committal but shook his head, and one remarked that "if you drove that thing down Woodward Avenue people would run for fright."

Standards of Appearance Are Not Fixed

At best, that which appears right is no fixed quantity. Cars at which you would laugh today were considered beautiful 25 years ago; I remember raving over some of them myself. We thought that our wives and sweethearts looked "just lovely," 25 years ago, in clothes which would make us laugh today.

As S. D. Waldon used to tell us years ago, when he was directing our engineering work at the Packard plant, "If a design is mechanically and fundamentally right, it will look right."

H. Ledyard Towle, elaborating at a recent S.A.E. meeting upon the old proverb, "Handsome is as handsome does," said:

> A peculiar thing about beauty is that, when you make a thing that functions properly, you have something that is beautiful. . . without trying to achieve beauty primarily.

Walter Dorwin Teague, the artist, in a recent address stated that a true artist strives "first for beauty of fitness and performance, and then for beauty of simplicity and gracefulness and flowing strength."

C. F. Kettering, facing the facts that "self-satisfaction is one of the world's worst diseases, and progress is hampered by the slow gait of the human mind," places the responsibility upon the engineer for "keeping the public healthfully dissatisfied." As a warning, he adds that "it often costs a lot more not to make a change than to make it."

The point that I am trying to emphasize is that, right here and now in this year 1931 of the "great depression," there is a crying need for improvement in the efficiency, economy and attractiveness of the automobile. We have general knowledge from which we can readily develop specific designs that will cut the gasoline consumption in half, and at the same time give more beautiful appearance and increased riding comfort.

That the public is and has been for a long time interested in the subject cannot be disputed. As long ago as 1913, the *Scientific American* published an article

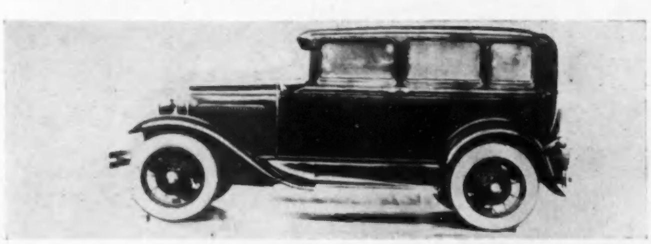


FIG. 6—WIND-TUNNEL TEST MODEL OF A CONVENTIONAL SEDAN

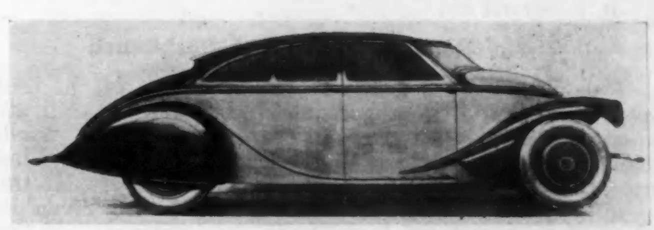


FIG. 7—WIND-TUNNEL TEST MODEL OF FISHLEIGH TEAR-DROP CAR

deploring the handicaps which prevented the automobile engineer from making "radical innovations" when desirable, saying:

> The conservatism of the majority of the human race resents upheavals of any kind, preferring a gradual elimination of the undesirable. The change from carriage body to automobile body therefore had to be made slowly and at the present time we have about arrived at the half-way station. The automobile of the future will no more look like the motorcar of today than the limousine of 1913 looks like the dos-à-dos carriage of 1896. In outward appearance, the car of the future will resemble a submarine boat on wheels more than it does a carriage.

Yet the general appearance and arrangement of closed cars has been little changed in the 18 years since the foregoing was written; and we hesitate now, not because we do not know what ought to be done and how to do it, but because the next desirable step seems to involve something of radical departure both in appearance and in arrangement of mechanical units, especially that business of moving the engine from the front to the rear. I am inclined to the view, however, that even

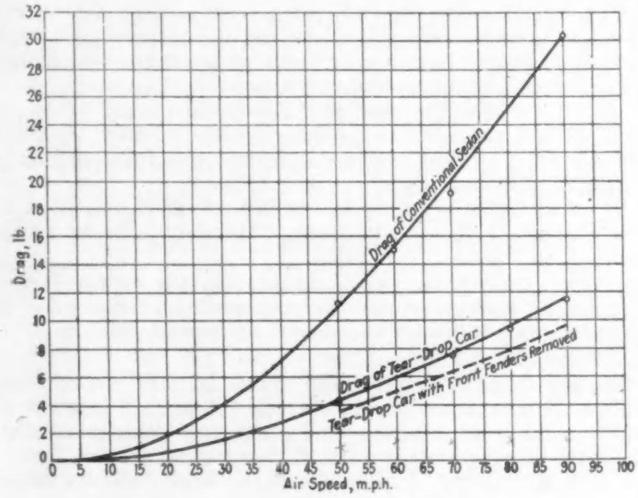


FIG. 8—RESULTS OF TESTS ON MODELS SHOWN IN FIGS. 6 AND 7

in automobile design for the fickle "Mr. and Mrs. Public," there are times when radical steps in improvements are both desirable and necessary to preserve our status quo as the most favored suppliers of individual transportation. L. C. Hill, president of Dietrich, Inc., said in an S.A.E. meeting recently:

> I believe that automobile engines are going to be in the back of cars a generation from now. There is certainly no reason why we should sit behind racket, behind odors and all of the heat, and build a car backwards as we are really doing today. But how we are going to sneak them around back there, either underneath the car or over the top, without making the jump at one time and without the public knowing it, is beyond me.

Great Reduction in Wind Resistance

Following extended layout determination of the best possible chassis arrangement and building accurate quarter-size models, our interest centered in wind-tunnel tests to check or disprove our theories on wind resistance. You will be surprised, as we were, at the results of our comparative tests, which are given in Table 1 in pounds of drag for the conventional and the tear-drop models at air speeds of 90, 80, 70, 60 and 50 m.p.h. In the column at the right is given the ratio

TABLE 1—WIND-RESISTANCE TESTS ON QUARTER-SIZE MODELS OF CONVENTIONAL AND TEAR-DROP SEDAN DSIGNS

Air Velocity, M.P.H.	Drag in Pounds Conventional	Tear-Drop	Ratio of Drags
90	30.3	11.4	2.66:1
80	25.1	9.4	2.67:1
70	19.1	7.5	2.55:1
60	15.1	5.9	2.56:1
50	11.2	4.3	2.60:1

of the drag or wind resistance of the conventional sedan compared to that of the tear-drop car.

Two remarkable facts stand forth:

(1) The conventional sedan has resistance or drag due to the wind somewhat over 2½ times that of a car streamlined according to the design shown.

(2) The superiority of the tear-drop design as to decreased drag remains in approximately the same proportion, regardless of speed. In other words, the wind resistance of the conventional design is approximately 2½ times that of the tear-drop design at any speed.

These results are plotted in Fig. 8, showing again that the percentage advantage in wind resistance remains virtually the same regardless of speed. The dotted curve shows the values found in subsequent tests on the tear-drop car with front fenders and triangular fairings behind the front wheels removed. These tests indicated great possibilities in eliminating front-fender effect, both as regards drag and front-end lift.

Please bear in mind, in considering the results reported and the possible improvements indicated thereby, that this model was only our first guess, although it was a scientific guess, based upon considerable experience and study. Subsequent considerations have indicated changes which should decrease the air resistance by another 25 per cent and improve the general stability of the car at high speeds without sacrifice in appearance or comfort. Furthermore, a surprisingly large number of modifications of the general appearance can be made to suit individual tastes without serious sacrifice in efficiency. In this design, the location of the engine at the rear with drive to the rear axle is essential.

Details of Design May Be Varied

Fig. 9 shows one layout for a rear-axle combination, incorporating the engine, transmission and differential

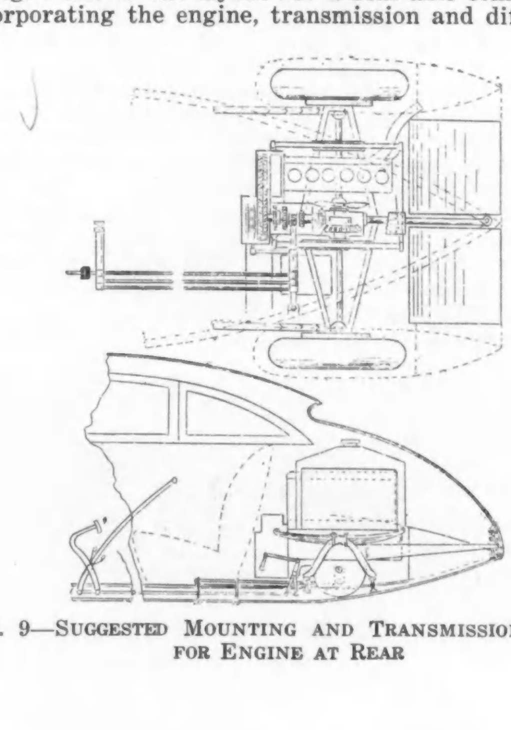


FIG. 9—SUGGESTED MOUNTING AND TRANSMISSION DESIGN FOR ENGINE AT REAR

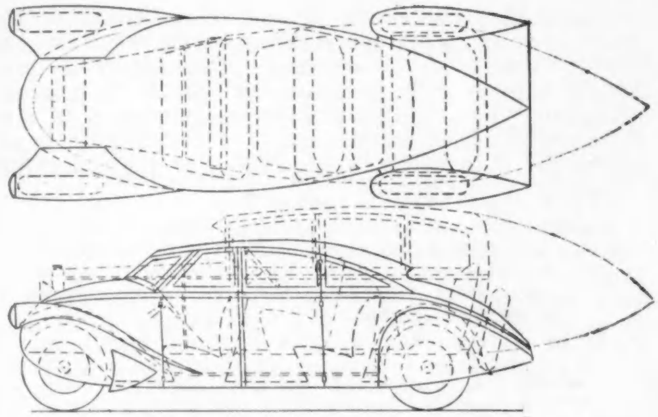


FIG. 10—SUPERIMPOSED OUTLINES OF CONVENTIONAL SEDAN AND TEAR-DROP CAR

in an independently sprung unit, over a split, dead rear-axle. The radiator and the gasoline tank are in the rear compartment. Neither this combination nor any of its details is urged, nor are they at all essential to the general idea; a dozen different designs of engine and rear-axle combinations have been laid out or built, and any one of these may be satisfactory for installation in the ample rear compartment of a tear-drop car.

The dimensions of the model tear-drop car are presented in Table 2, together with those of a standard small sedan and a standard large sedan of the same capacity, for comparison.

Fig. 10 shows a conventional medium-size sedan superimposed upon the tear-drop design. Having the same wheelbase and approximately the same over-all length, the differences in over-all height and location of the center of gravity and of the rear seats with respect to the rear axle are striking. Dotted lines at the rear indicate the tremendous overhang which would be necessary to streamline the rear end of the conventional car enough to reduce its rear-end drag to an amount that would be comparable with that of the streamline car.

The total resistance of an automobile at any speed is expressed by the equation

$$F = r + R \qquad (1)$$

in which F is the total resisting force and R and r respectively are the wind resistance and friction resistance of the car, all in pounds. The frictional resistance r increases somewhat with the speed, but it is nearly enough constant so that an average value can be used in preliminary calculations without objectionable error. The wind resistance R is the wind-tunnel-test figure for a full-size car. It can be approximated for a conventional sedan by the equation

$$R = 0.002\,AV^2 \qquad (2)$$

in which A is the frontal area of the car in square feet and V is the velocity in miles per hour and 0.002 is an approximate constant that has been well established by wind-tunnel tests.

The frictional resistance of a car of this size may be assumed to be 35 lb.

Having determined experimentally the frictional resistance and the ratio between the wind resistances of the two models, we can determine the total road resistance for both models at various speeds by means of Equations (1) and (2). The values shown in Table 3 were computed by means of these equations. It is interesting to note that the total road resistance of the conventional sedan varies from 1.7 to 2.3 times that of the tear-drop design at speeds from 40 to 90 m.p.h. As the horsepower and fuel required at any speed vary roughly as the total resistance to be overcome, it follows that the tear-drop car will run approximately twice as far on 1 gal. of gasoline as will the conventional sedan.

Accurate experimental tests to determine both the drag and the lift effects, both front and rear, have been conducted upon variations of the tear-drop model shown in Fig. 7. For different tests, the front fenders have been removed, the windshield angle has been filled in flush, the rear-vision-window angle has been eliminated, and a different contour has been used at the front under the body. These tests point the way to further improvement, but details are thought not to be pertinent to the presentation of the general problem.

TABLE 2—DIMENSIONS OF TEAR-DROP AND CONVENTIONAL SEDANS

	Tear-Drop	Conventional Small	Conventional Large
Wheelbase, in.	125	103½	136
Road Clearance, in.	8½	8¾	8½
Over-all Height, in.	60	71¼	74¼
Over-all Length, Including Bumpers and Trunk, in.	194	156	212
Over-all Width, in.	68	67	70
Inside Width of Body, in.	56	55	58
Tread, in.	56	56	58
Height, Ground to Floor, in.	10	22½	26
Height, Ground to Bottom of Window, in.	42	48	51
Height, Seat Cushion to Roof,[a] in.			
Front	37	35½	37
Rear	36	35	35½
Maximum Height of Side Glass, in.	12	14½	14
Capacity of Storage Space, cu. ft.	8½	3¾	6
Frontal Area, sq. ft.	23	24½	26
Diameter of Wheel Rim, in.	18	19	20
Diameter of Tire Section, in.	6	4.75	7

[a] Seat dimensions, seat spacing and head clearance in the tear-drop sedan are the same as in the conventional large sedan.

TABLE 3—ESTIMATED TOTAL ROAD RESISTANCES OF CONVENTIONAL AND TEAR-DROP SEDANS

Speed, M.P.H., (V)	Total Road Resistance, Lb., (F) Conventional	Tear-Drop	Ratio of Resistances
90	425	182	2.3:1
80	342	150	2.3:1
70	270	127	2.1:1
60	208	103	2.0:1
50	155	81	1.9:1
40	112	65	1.7:1

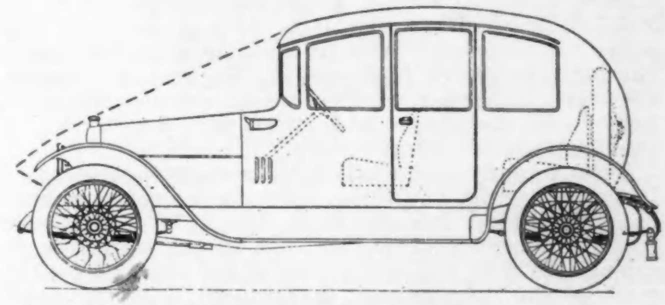


FIG. 11.—ANTE-BELLUM STREAMLINE BODY DESIGNED BY J. J. IDE

Why Attempts at Streamlining Have Failed

From the facts that crude attempts at streamlining with automobiles have been unsuccessful in the past and that the public has not been enthusiastic over them, it does not follow that full streamlining will not be successful today and tomorrow when carried out in a scientific and artistic way. Obvious reasons existed for these past failures. Some of these reasons and ways of eliminating them will be considered in the following:

(1) Streamlining attempts in the past were more or less grotesque or at least lacking in beauty and symmetry of line and contour.

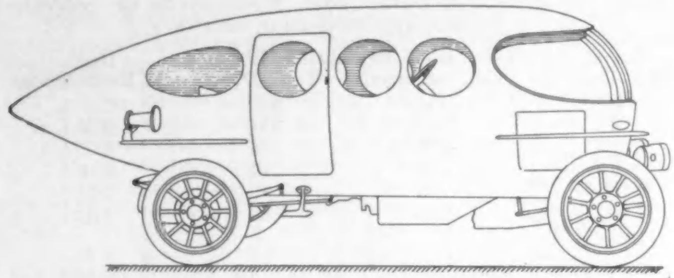


FIG. 12—ITALIAN STREAMLINE CAR OF 1915

Fig. 11 shows a streamline body which was illustrated in *The Automobile* of May 1, 1913. This car, like most 1931 models, would not be a bad streamline form if its front end were smoothed out as suggested by the dash line, the seats turned around and the car run backward. A streamline body which was built in Italy in 1915 after designs by Count Marco Ricotti is shown in Fig. 12. The effect of streamlining is indicated by the fact that the maximum speed of this chassis without body was 65 m.p.h., while with the body shown the speed was 80 m.p.h.

Several streamline cars designed by Paul Jaray have been illustrated in the S.A.E. JOURNAL recently[2]. These cars were somewhat crude and grotesque because of his attempt to make a streamline design with the engine in the conventional position in front, but their wind resistance was only about one-third that of contemporary German cars of the same passenger capacity. In other words, his wind-tunnel tests established a constant for use in Equation (2) which was only one-third that required for the conventional closed car. Consideration of the Bluebird, with which Capt. Malcolm Campbell set a world's automobile speed record of 245.73 m.p.h., shows that it is unusual in shape and style. It is unusual also in its adaptability to travel through the air at high speed. We may well pause, therefore, to ponder whether we do not pay too much homage to the shapes and styles with which we are familiar, but which are wrong.

Tests recently conducted[3] in the aeronautic laboratory in the University of Detroit show that even the amount of streamlining introduced in the 1931 Reo Royale made a reduction of 13 per cent in air resistance in comparison with the 1930 model of the same car. Still, most of the improvement in this car is at the front end, whereas the all-important drag in automobiles at high speed is due to the conventional vertical rear end.

(2) Formerly neither the general public nor automobile manufacturers were accustomed to streamline structures. Now they are accustomed to them and like them.

(3) The advantages to be gained by the streamlined and rearranged automobile were formerly unknown. Authentic data upon these advantages now are available.

Stability of Car Can Be Improved

A body like that of an airship or an airplane, traveling freely through the air or water without directing or controlling contact such as is afforded by wheels on a road-bed, depends to a considerable degree for its stability and smooth directional travel upon the relative locations of its center of gravity and its center of resultant wind pressure. If it is so designed and proportioned that the center of gravity is ahead of its center of wind pressure, a righting couple results whenever it tends to deviate from its direction of motion, tending automatically to return the body to its original alignment. This is of considerable importance in airplane and dirigible design; but it is not believed to be critical in a tear-drop automobile, for the following reasons:

(1) Stability and smooth directional travel of an automobile can be maintained with no considerable righting couple because of the directing and controlling contact of the loaded front wheels on the road-bed.

(2) In the tear-drop car, the front end may be so designed as to give, at say 60 m.p.h., a downward component of the wind pressure which will load the front wheels sufficiently to assure directional control at this speed. This downward pressure is added to the front-axle weight of the car and increases with increased speed. It also decreases with decreased speed, enabling exceptionally easy steering for low-speed operation. The location of the center of gravity of the car and its load is thus not of critical importance in the matter of steering and directional control in the tear-drop car as it is in conventional sedans and in airplane or dirigible bodies.

(3) The front axle can be well loaded and the center of gravity should be far enough forward—with the forward seats located well forward in the body; with ample storage space in the extreme front end in which will be located the extra wheel and tire, tools and baggage; and with the rear seats, the battery and a part or all of the engine unit located ahead of the rear axle—to at least avoid any noticeably disturbing couple at high speed.

Possibilities of the New Design

Present-day automobiles were designed, as to both appearance and general arrangement, 20 to 30 years ago, when speed and operating economy were relatively of little or no importance. Naturally and rightly, aerodynamic conditions of adaptability to high-speed travel through the air were not then considered. Today, high speed, economy and maximum comfort are demanded. The automotive industry and the automotive engineer can supply this demand with the rear-engined streamlined tear-drop car having a low center of gravity. Following are the outstanding advantages which will result from such a change in design:

(1) Twice as many miles per gallon of gasoline, because of reduced wind resistance

(2) Clear vision, resulting from removing the engine unit from the front end

(3) Elimination of noise, vibration and odors from the engine, due to its location behind the passenger compartment and suspension on separate springs

(4) Improved riding comfort, because of the low center of gravity and the location of the seats between the axles

(5) Trussed unit body construction, with elimination of conventional chassis frame

(6) Low cost; body, chassis and assembly being simplified

(7) Beauty and grace, due to artistic streamlining

Results such as indicated in the foregoing cannot be had by rounding a corner here and adding a molding there or by reworking all of the production dies which are not entirely worn out.

[2] See S.A.E. JOURNAL, March, 1931, p. 291.

[3] See S.A.E. JOURNAL, July, 1931, p. 29.

THE DISCUSSION

A. LUDLOW CLAYDEN[4]:—Visibility from the driver's seat of the typical car of today seems to be much poorer than from older cars. This impression was strengthened last year by driving a considerable number of miles in a very old car. It may be advisable in the tear-drop design not to take the fullest advantage of the possibility of placing the passengers low, because the altitude of the driver's eye and interference with the fore part of the vehicle have a great effect upon visibility.

Range of vision, which is particularly important for high-speed driving, is greatly affected by altitude. It seems as though Mr. Fishleigh's models would give an improvement in the ability of the driver to see the front fenders, which is very helpful in parking and handling in close quarters.

H. L. HORNING[5]:—At least six freight lines are being conducted in California in which trailers are used to utilize the maximum legal limit of weight, which is 68,000 lb. The frontal area was found to be the controlling factor in gasoline consumption. These 34-ton trains are traveling the same number of miles per gallon of gasoline as some of the fashionable 16-cylinder cars can make. We have been able to tell the direction of the wind by the change in gasoline consumption. The resistance is found to be greater when the wind is blowing at an angle on a long truck than when it is blowing head on. These trains approximate streamline forms and are reaching an economy as high as 154 ton-miles per gallon of fuel in daily service.

An experience in testing a six-cylinder engine in a small car at 68 m.p.h. showed me that the wind could throw the car at least two feet to one side. A car intended for high-speed driving should have inherent directional stability, even if it has to have a tail-fin to keep it on a straight course.

Improvements in Comfort and Cost

ROSCOE C. HOFFMAN[6]:—Engine heat is an important item, particularly when driving in hot weather. With the cowl scoops and windshield open, insects and bees are very annoying and add considerably to the danger of driving. It is possible to build a car with the engine at the rear and a fixed windshield and to ventilate it thoroughly through a screen ventilator.

Builders of rear-engine cars will encounter difficulty in securing directional stability if the engine is placed to the rear of the rear axle. It is quite possible that a large fin may be required at the rear of the body to restore the directional stability that would be lost by having the center of gravity too far to the rear of the center of pressure.

A rear-engine car can be built exceptionally low; however, I prefer the top height to be from 64 to 67 in., and with these heights a body can have head room of 46 to 48 in. with seat cushions 13 to 14 in. high. Doors may be 32 to 35 in. wide; and entrance to the rear compartment will be very accessible, as the rear door is entirely in front of the rear fender and its wheelhouse.

A car with the engine at the rear can be built that will give the passengers a more comfortable ride and less noticeable vibration than in the conventional car, and no noticeable engine heat or odors. It will weigh less and it can be produced at a materially reduced price.

AUSTIN M. WOLF[7]:—We all agree that four-wheel brakes are essential to safety in stopping; I firmly believe that four-wheel driving is essential to safety at high speed. This would necessitate either duplicating the powerplant or transmitting the power from one end of the car to the other, regardless of where the engine is located. All of this must be considered as it affects body design.

Probably the impression is general that the streamlining in the cars of the Jaray[8] design would not be as efficient as a purely tear-drop design. I believe that a number of streamline forms can be combined to obtain a more acceptable appearance than the basic tear-drop and at the same time keep the air resistance low; in fact, Captain Campbell's racing car embodied a combination of two or three such forms.

MRS. L. O. HUMBLE[9]:—Is not a streamline car safer than cars of conventional form? I believe that under some wind conditions at high speed the drag is localized on one side of the rear of the car, and a slight change in the direction of the wind would cause an instantaneous shifting of the center of resistance to the opposite rear quarter. Aerodynamic authorities state that large changes in the angle of attack cause little or no shifting of the center of resistance of a streamline car.

Insurance statistics in New York City show that thousands of dollars per day are lost because of damaged fenders and bumpers. If automobiles, particularly those of the tear-drop type, could have a large guard strip located at a height prescribed by the police, to protect them at the sides as well as at the rear, much damage would be saved when cars rub against one another.

Some Difficulties To Be Faced

MAURICE OLLEY[10]:—Speed can be increased only fractionally by increasing the power, while it can be increased in multiples by streamlining. We cannot fail to be sold on building cars with decreased air resistance, which we still call head resistance although we know it to be due principally to lack of a tail.

The advantages of rear-engine cars are so obvious that we must consider the possible difficulties. The first is in selling. How can we sell a rear-engine car against an appeal to the instinct of fear aroused by a rival salesman who would call it "soft-nosed"?

Changes in springing may introduce other difficulties. Presumably we shall continue to make the rear springs softer than the front because the rear passengers, who generally buy the car, would be closer to the rear axle. Placing the engine at the rear will help because the percentage of variation in deflection between no load and full load will be reduced, but the short drive that will be involved may be difficult with the soft springs. At the same time, the greater variation in deflection of the front springs will accentuate problems in steering geometry. Front shackling of the front springs and nearly perfect geometry, or some radical change in steering design, will be essential.

Some of the short-nosed European cars, in which the driver sits close to the front wheels, give a severe lateral acceleration to the front-seat passengers in turning street corners. This unpleasant condition will exist in rear-engine cars unless the wheelbase is long enough to allow considerable distance between the passengers and the front wheels. Bucket seats reduce the unpleasant-

[4] M.S.A.E.—Research engineer, Sun Oil Co., Philadelphia.

[5] M.S.A.E.—President, general manager, Waukesha Motor Co., Waukesha, Wis.

[6] M.S.A.E.—Automotive engineer, Detroit.

[7] M.S.A.E.—Consulting engineer, Plainfield, N. J.

[8] See S.A.E. JOURNAL, March, 1931, p. 291.

[9] City of Washington.

[10] M.S.A.E.—Engineer, Cadillac Motor Car Co., Detroit.

ness of turns in such cars. Increasing the moment of inertia of cars may seem desirable, to reduce pitching, but a rear-engine car may have too great a radius of gyration, resulting in severe bouncing and striking the axle at high speed and danger of a "flat spin" on corners.

In fairness, we should list some of the material and artistic faults of present cars as follows: rear passengers do not ride *in* them but are housed in a sort of a sequel; innumerable ugly and costly tin petticoats of no determinate shape and no aerodynamic value are required; present designs lack a sensible and economical division of function between coach work and chassis and adequate provision for luggage or spare wheels within the structure; and there are too much weight, heat and engine power and inadequate radiation.

Automobiles Should Have Individuality

If we will give as much attention to making engines short as we have given heretofore to making them long, aircraft engines pointing the way, we may be able to solve all these difficulties without changing the location of the engine. The automobile business has reached the stage where only a minute inspection will distinguish one make of car from half-a-dozen others. I believe that we should change this condition and make more difference between the cars, so that the buying public will begin to argue about them as they used to do.

I have only one ground for disagreement with Mr. Fishleigh, and that is in regard to using the body shell as a substitute for the frame. One of the objections to this is that the coach work is dominated by style change and must vary while the frame depends upon mechanical facts and should not be allowed to vary. In addition, using the body shell as a frame structure would necessarily result in vibration and tire noise being telegraphed to the body panels.

A far better scheme is to build a vertebrate car having a chassis frame consisting of a single large-diameter tube. This would dispose of objection to the rear-engine car as a soft-nosed vehicle, because an engine rigidly attached to the rear end of such a tube would be just as effective a battering-ram in road arguments as in the present vehicle.

S. P. MARLEY[11]:—Mr. Fishleigh has shown differences in drag between the conventional car and his design in a ratio of more than $2\frac{1}{2}$:1. Would not this ratio be reduced if a comparison were made with a conventional coupé which has some streamlining back of the seat?

How much difference is there in the resistance of a sedan according to whether the windows are closed or open?

Is the drop at the rear of Mr. Fishleigh's design for the purpose of accommodating a rear window?

Tear-Drop Has Not Streamline Form

F. W. PAWLOWSKI[12]:—Mr. Fishleigh is to be congratulated for his contribution to the literature on a vital problem, including an esthetically pleasing design of motor-car. However, I entreat him to drop that mournful and totally erroneous term "tear-drop" in reference to streamline shapes.

The shape of a tear-drop or a drop of water has absolutely nothing to do with aerodynamics; it depends entirely upon the surface tension of the liquid. When the tear drop becomes too large and heavy to hang onto its source it breaks off, first developing a pointed stern while the bow retains its spherical shape. This can be confirmed by experiment with a medicine dropper. The drop retains this shape, which resembles an onion more than anything else, only as long as it hangs onto the dropper. The length of this shape is only a little greater than its diameter, while the length of a streamline body is usually several times its diameter.

While falling through the air, the shape of a drop of water is governed almost exclusively by the surface-tension forces which, for water and the majority of liquids, are of much higher order than the air pressures. Photographs of a drop falling through the air, made by the U. S. Army Ordinance Department with equipment used for photographing rifle-bullets in flight, show that the drop is subject, while falling, to rhythmic, elastic pulsation between the forms of an oblate and a prolate spheroid. This pulsation takes place along the diameter parallel to the direction of falling, and the change in that diameter is say 20 per cent. The pulsation is set up by the periodically discharging eddies back of the drop, and at no time does the drop assume a shape even vaguely resembling a streamline body.

When a tear drop or water drop slides down a vertical or steeply inclined surface, adhesion between the drop and the skin causes it to assume a more elongated form, resembling entirely accidentally and rather crudely one-half of a so-called streamline body.

Ideal Form Shorter for Air than for Water

The fish forms reproduced in Mr. Fishleigh's paper apparently show the side views of bodies of rather flat fish and do not give a true idea of the relation between their length and cross section. F. W. Lanchester made a similar study of fish bodies about 24 years ago in England, converting them into equivalent and equally long bodies of revolution. He thus established the ratio between length and diameter for streamlining in water as about $7\frac{1}{2}$:1; but these are not applicable to air, which has a viscosity 20 to 30 times as great as that of water. Considering the bodies of birds without their heads, which are shaped primarily for other than aerodynamic requirements, the ratio of length to diameter is often only about 2:1. We now know that the correct ratio in air is about 3:1.

Cold-blooded fish could afford to use the more elongated shapes to reduce the resistance to motion in the much less viscous medium; but the warm-blooded bird was obliged to develop shorter and fuller shapes because of the higher viscosity of air, and they went even farther to cut down the cooling area of their bodies. This means that the birds have made a very judicious compromise between the conflicting requirements of aerodynamics and physiology.

During the last decade, Dr. A. F. Zahm, the former director of research for the Navy Aircraft Bureau, made, in the Washington Navy Yard wind-tunnel, a most complete and systematic study of streamline bodies suitable for airship design, and he has furnished new proofs that the bodies of least resistance in air are much shorter than those in water. Ralph Upson has used a length-diameter ratio of about three in his Metalclad dirigible.

Locating the engine in the rear might reduce the engine noise a little, but any vibration can be telegraphed to any part of the body just as readily from the rear as from the front. Heat and odors, too, might easily be carried forward to the middle window of the body by the reverse flow inside the so-called boundary layer.

Not much can be predicted about the effects of modifying the bottom of the body to make it more nearly parallel to the road surface until the fundamental question shall have been decided as to whether the body of a vehicle moving close to the ground should be considered aerodynamically as a whole body or one-half of a body.

Some of the aerodynamic terms in the paper are not quite well chosen or properly used. "Rear-end drag," for instance, does not exist, although there is an eddy-

[11] M.S.A.E.—Research engineer in petroleum technology, Mellon Institute of Industrial Research, Pittsburgh.

[12] Guggenheim professor of aeronautics, University of Michigan, Ann Arbor, Mich.

making resistance. What Mr. Fishleigh calls frictional resistance has been referred to by a number of writers as road resistance, because it is due to rolling on the surface of the road and depends upon the character of the road, or simply as rolling resistance. Energy losses due to friction in the transmission should be treated in the same way as frictional losses in the engine. We are interested primarily in the net motive power delivered to the driving wheels and the resistance to motion which, in this case, can be divided into road resistance and air resistance.

The author assumes a road resistance of only 35 lb. This seems to be estimated on the basis of 10 lb. per 1000 lb. for a total weight of 3500 lb., while various authorities say that the value should be two to three times as much at speeds of 40 to 90 m.p.h. If a figure of 25 lb. per 1000 lb. is assumed, the ratio of total resistance shown in Table 3 would be reduced from 1.7:1 to 1.4:1 at 40 m.p.h. and from 2.3:1 to 2:1 at 90 m.p.h.

Wind-Tunnel Tests of Car Models

W. E. LAY[13]:—During last year, a study of the possibilities in the reduction of air resistance of automobile bodies was begun in the wind-tunnel of the University of Michigan. The tests so far have been of a general exploratory nature, including a study of test methods as well as the aerodynamic characteristics of various body shapes.

One of the difficult problems in wind-tunnel tests is provision for the road surface. The so-called ground effect has received considerable attention in the take-off of heavily loaded airplanes, but simple and satisfactory test methods have yet to be devised. Some arrangement of a moving belt is naturally suggested, but uncontrollable flapping made its use impracticable. Tests have also been made using a flat plate, but the retarded flow of the air in the boundary layer next to the plate surface made its use questionable. The so-called reflection method, using duplicate models placed wheel to wheel, offers a more reasonable solution, but it is rather expensive as it requires a complete duplication of all the models investigated. Several models were tested by four different methods, as illustrated in Figs. 13, 14 and 15, with the following rather widely divergent results, expressed in percentages of data obtained from the flat-plate method with boundary layer removed:

	Per Cent
Model free (no road surface)	111.0
Using flat plate	86.8
Flat plate, boundary layer removed	100.0
Reflection method (duplicate models)	117.2

Although the results obtained by the different methods show considerable discrepancy among themselves, the data as to the percentage of improvement due to streamlining are fairly consistent when measured by all four methods. These tests began with a simple rectangular box shape, with length, height and width proportional to the dimensions of a typical 1930 sedan. The next model had all sharp edges rounded. A middle section of this body was then provided with a series of different front and tail sections. Studies were made of different windshield shapes and methods of housing the wheels, as well as the effect of cross winds. Some time was spent in studying lines of air flow over typical shapes. We not only measured the drag; we found some very interesting facts about the lift and moments acting on the body at high speeds. Typical values of the streamline coefficient K in the formula $R = KAV^2$, obtained by up of the flat plate with the boundary layer removed, are as follows:

Box shape with sharp corners and edges	0.00184
Box shape with rounded corners and edges	0.00129
1930 model sedan	0.00132
Streamline model sedan	0.00068
Fully streamlined form	0.00021

Altogether, 29 models were tested, including a scale model of a 1930 sedan and two streamline sedan models which had both excellent aerodynamic properties and pleasing appearance.

Vision, Economy and Stability

W. T. FISHLEIGH:—I quite agree with Mr. Clayden that the height of the driver's seat is a matter of compromise between good vision ahead, which is increased with height, and riding comfort, which increases with lowness; and that some recent models are faulty if not dangerous in the matter of clear vision. Regardless of the ultimate height decided upon for the tear-drop car, the front end of the body is so rounded off by

[13] M.S.A.E.—Professor, mechanical engineering, in charge of automotive laboratory, University of Michigan, Ann Arbor, Mich.

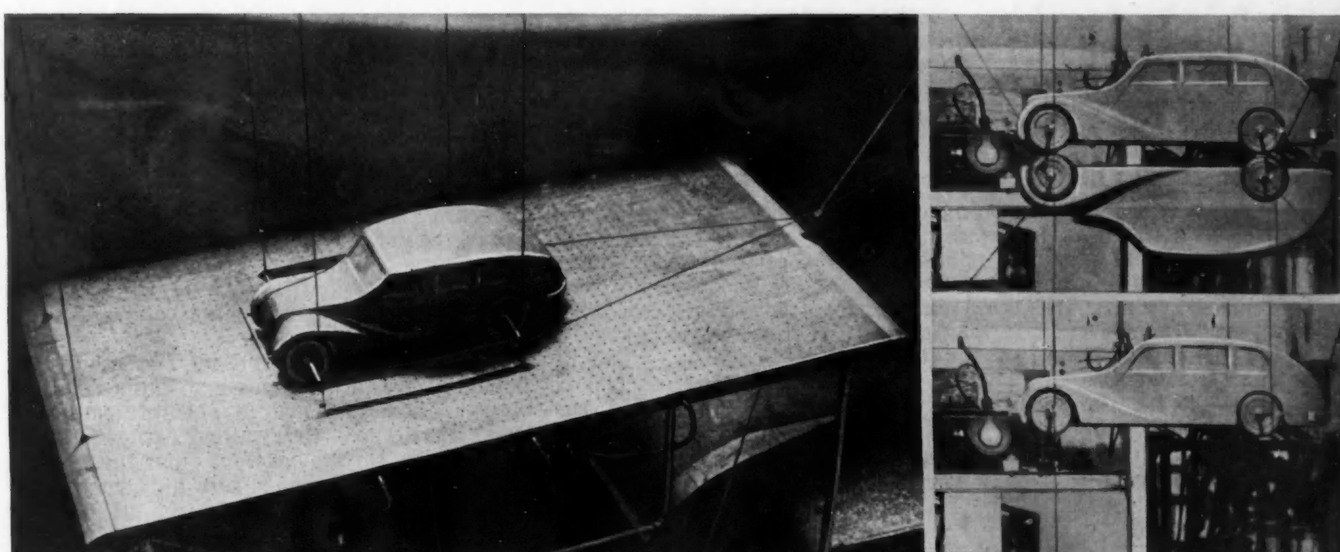


FIG. 13—WIND-TUNNEL TESTS AT THE UNIVERSITY OF MICHIGAN

Above—Testing with a Flat Plate. When the Effect of Removing the Boundary Layer Is Desired, Air Is Sucked through the Holes in the Plate

Upper—Reflection Method, Using Two Models
Lower—Testing in Free Air

streamlining that clear vision is readily given to the driver, not only of the road immediately ahead, but of his fenders for parking and close traffic control.

Directional stability at high speeds seems to have been considered by Mr. Horning, with many others, as if the tear-drop body were a free body floating through the air like an airship, in which directional stability and control depend primarily upon the relative locations of its center of gravity and the resultant of resisting wind pressures. This consideration is far from controlling in the case of automobiles travelling on the road, for two reasons: first, whatever weight there is on the front and rear wheels gives steering and directional control; second, by proper design of the front end of the body, a downward component of wind pressure can be loaded upon the front wheels sufficient for satisfactory steering and directional control at the maximum speed. As this wind loading decreases with decreased speed, steering is proportionately easier at the lower speeds and very easy at ordinary city-driving speed. We see no spectre of tail-fins hovering about.

Mr. Olley is borrowing trouble when he worries about the public calling the tear-drop car soft nosed. The whole front end of the body is a trussed framework, with the main frame at the belt line. A husky bumper, attached directly to that frame, four or five feet in front of the driver, gives all the sturdiness and protection that one could desire for any use short of a battering-ram. Two ¼-in. rods attaching the engine to the frame would preclude any possibility that the engine might break away from its location behind the passengers in the most severe crash.

A wheelbase of 125 in. has been found to afford ample space for the passenger compartment between the axles; ample room for the engine at the rear; more than sufficient space ahead of the driver for such things as extra wheel, luggage, golf bags and tools; and ample streamlining both front and rear, within an over-all length comparable with that of present cars of the same wheelbase.

Uselessness of Chassis Frame

One of the great production and weight-reducing advantages of the tear-drop car is the elimination of the separate heavy and useless chassis frame. The tear-drop car has three major production assemblies: the body, the front axle and steering assembly, the rear axle and engine assembly. Its bridge-truss construction lends itself to both rigidity and light weight. The two other assemblies are attached thereto in final assembly by means of the springs. Different bodies may be given all the variations and individuality in the world, so long as suitable standards for attachment of the front and rear-axle assemblies are provided. The engine and transmission being separately spring-mounted in the rear-axle assembly, there is no possibility for noise, rattle, vibration and odors coming directly to the body as in present conventional cars.

Answering Mr. Marley's questions, the coupé of today is somewhat, perhaps 25 per cent, better than the sedan as to rear-end drag. The wind resistance of a sedan with all its windows open is measurably greater than with the windows closed, as our tests on all models were run, but we are not able to give exact figures. The depression in the top at the rear was necessary for a rear-vision window.

I regret that Professor Pawlowski's absorption with inconsequential technicalities governing the tear-drop causes him to lose sight of the inspirational and promotional value of a captivating name. It is difficult to agree with the theory that the tear drop in its fall is subject to rhythmic pulsation in form between an oblate and a prolate spheroid. The front end looks to me more like a hyperbolic paraboloid or a hyperboloid of revolution of one nappe.

The fish forms shown in Fig. 3 are some of those studied by the British Admiralty in arriving at the most efficient forms for airships, illustrated in Fig. 4. The upper model in Fig. 4 has a length-diameter ratio of 4½ to 1 and the second a ratio of 5 to 1. In our tear-drop car we cut the ratio to 3 1/3 to 1, which agrees with the latest experimental test figures and with that of Professor Pawlowski.

The statement that any vibration can be telegraphed to any part of the body just as readily from the rear as from the front does not of course apply in the case of an engine that is mounted on the rear axle by springs entirely separate from the body. There is even less logic in the statement that the heat and odors from an engine at the rear would be carried forward to the windows by "the reverse flow inside the so-called boundary layer."

Rolling Resistance and Wind Resistance

The assumed figure of 35 lb. for total road resistance is not an average for cars designed with little or no attention to rolling resistance; neither is it based upon present gross weights, which can be substantially reduced with the bridge-truss type of body. It was arrived at as follows: The total weight was assumed at 2800 lb., which is entirely reasonable for a five-passenger sedan of the bridge-truss type that is possible in a tear-drop car; the road resistance—assumed to be 12.5 lb. per 1000 lb. of car weight, which is possible in any first-class car today—was arrived at from tests upon medium-priced cars. The suggested figure of 25 lb. per 1000 lb. of car weight might apply to cars of antiquated design or production, but not for 1931 cars. The figure of 35 lb. total road resistance can be readily realized tomorrow in a tear-drop car if the design and production are executed with due regard for the importance of this figure to the owner's pocket-book.

The comparative figures for wind-resistance tests run on models with various set-ups, as outlined by Professor Lay, are extremely valuable. They clearly show that, if the wind resistance of one design is of the order of 2½ times that of another, it does not matter much which method we use for comparative testing. So much time should not be lost in academic argument over the relative superiority of the several methods that we miss the main point, which is the tremendous possibility for improvement. Our tests were run with flat-plate set-up in the wind-tunnel. A real opportunity is open to Professor Lay and the University to conduct a research of tremendous value to the industry as follows: Construct wind-tunnel models of conventional and tear-drop sedans, which are scale duplicates of full-size cars constructed for road tests. Run comparative wind-resistance tests on the models in the wind-tunnel by the free-model, flat-plate and reflection methods. Compare these with wind-resistance tests of the full-size cars actually run on the road, and thus establish which method of wind-tunnel testing best approximates road results and how closely road results can be expected to agree with comparative wind-tunnel figures.

The figures experimentally found by Professor Lay for the coefficient K in the well-known formula for total wind resistance, $R = KAV^2$, are in absolute value all noticeably lower than those determined experimentally by Jaray, Agg and Wolfard, Lockwood, and the writer. Proportionately, however, there is fair agreement, for example, between Professor Lay's figures of 0.00132 and 0.00068 and the writer's figures of 0.0020 and 0.00077, considering the fact that different models were tested. The important point, however, is that Professor Lay's tests agree with the writer's in pointing to tremendous improvements in wind resistance, and therefore in gasoline economy, which lie immediately ahead.

Some Questions about High-Speed Driving

Semi-Annual Meeting Paper

By J. E. Hale[1]

SINCE automobile manufacturers have put into the hands of owners super-performing vehicles, they should recognize their responsibility to take the necessary steps of teaching the owners how to drive these cars. I am putting it this way because, after much thought, I am convinced that very few people have any moral right to drive the uptodate cars on the highways at anywhere near the maximum speeds of which they are capable. I include myself in this category.

True, I can sit in the driver's seat with my hands on the steering-wheel and my foot on the accelerator pedal and guide the car when it is running from 60 to 80 m.p.h. on a road that is wide, dry, smooth and free from traffic, intersections, bumps and holes, and with good visibility; but this is only a small part of what constitutes the sum total of driving an automobile. On the other hand, the combinations of weather conditions, highway and traffic situations, car characteristics and driver reactions, which set up all manner of variations that constitute hazards of varying degrees, are almost numberless.

I am not discussing in this paper the handling and manipulation of a car at what might be called ordinary city or country driving-speeds, but I believe that in driving at speeds of 60 m.p.h. and over, so little is actually known about the proper moves to make under different emergencies that the owner who operates his car at these higher speeds is taking unreasonable chances since he does not have a proper understanding of what to do to get out of a tight place. Also, dwelling on the thought that the real answer to the problem lies in having the driver always drive in such a manner that he has the car under control at all times is of no use. The point of this paper, on the contrary, is just the opposite. The discussion presupposes that the driver is pushing the car at speeds beyond those which are reasonable to call within control.

Moreover, he is doing it because car manufacturers have placed in his hands a vehicle of great power which is capable of traveling at these high speeds; a car that, because of soft springs and deep seat cushions, takes the average highway in remarkable comfort; moreover, the engine and running gear of these new cars are smooth and quiet. For the owner to make the car go faster than he realizes is very easy. The smoothness and absence of noise definitely invite him, in a subtle way, to take advantage of the capacity of the car.

Car manufacturers, having provided the public with high-speed cars, should teach the owners how to drive them safely.

Relying upon the driver's intuition to do the correct thing in an emergency is not feasible.

Weather, traffic, highway and vehicle elements combine with driver mentality, emotions and reactions to produce varying degrees of hazard.

Four-wheel brakes are much safer than two-wheel, but their application is more complicated.

Danger from blowouts has been overestimated.

Mental and physical fatigue cause the majority of accidents.

Constant attention on the part of the driver can do more than anything else to reduce accidents.

Speed up the slow cars instead of slowing down the fast ones.

Cannot Depend on Intuition

Some people may advance the argument that drivers acquire by experience a gradually developed instinct, subconsciousness, intuition, or whatever they may call it, of handling a car under emergency conditions. Possibly a few people can train themselves to do the right thing instinctively or subconsciously, but I believe that only a very small number can depend on this, and that to do some educational work, which should be based on experiments and tests, is indispensable.

In my own experience I can recall several times when I have been in a tight fix, and I did not find any instinct or subconsciousness doing anything about it. On the other hand, I was conscious of thinking as hard as I could and questioning just what I ought to do; also, I was conscious of actually trying to reason out which of several maneuvers might be the most likely to get me out of the difficulty. On the brink of a serious driving predicament certainly is not the time to have to do any profound or logical reasoning. Neither is depending on instinct sensible if that phase of human make-up has no background for functioning under such cases. I feel satisfied, in my own case, that if I had had a clear idea of what moves I should have made, I was calm enough to have put them into effect. The facts were that I simply did not know the proper course of action.

I do not know the answers to many of the questions I shall raise; and if the industry as a whole does not know the answers, the car designers have a definite responsibility to try to get the answers, to educate car owners so that they can recognize the problem and be prepared to solve it promptly when it arises. When these emergencies happen, the time in which to act is so short that the driver must do the correct thing the first time and practically instantaneously. This means that all the preparatory thinking must be done ahead of time and must be thoroughly understood. Our problem is to master and teach the technique of decelerating and steering the car under conditions of danger.

[1] M.S.A.E.—Chief research engineer, Firestone Tire & Rubber Co., Akron, Ohio.

Making a Quick Stop

To do this, drivers must have a much better understanding of how to apply the brakes and must be taught to recognize and evaluate the decelerating characteristics of the different types of road surface. To be in a position to do this, they must possess a clear understanding of the coefficient of friction between tires and road surfaces involving the different characteristics of road surfaces when wet, dry and snowy and also the different conditions of tire wear.

Table 1 shows the distance needed to stop cars from different speeds. While information of this character is probably in the files of every car designer, I do not believe 1 owner in 10,000 has any conception of the distance and time needed to bring a car to rest. Giving this information to the driver will be a very effective way of making him realize the dangers. Furthermore, the great differences in traction control on different road-surfaces is something fundamental with which every car owner should be acquainted.

Regarding this matter of trifling with that law of physics which says that a body in motion will continue to move in a straight line unless acted upon by some external force, who is there who thinks that he can guide and steer 4 or 5 tons of matter at 80 m.p.h. through all the curves and angles of our varied highway and traffic conditions without advice and counsel? Can it be that the few clever drivers alone can do this, and the rest of us have not a chance? Personally, I believe the rest of us have a chance if that chance shows up in the form of proper instruction and training.

Points upon Which Instruction Is Needed

The following questions are typical of the subject matter on which instructions and advice are needed:

(1) How is the driver to know whether he has locked his brakes?

(2) How should the brakes be applied to give the maximum decelerating effect?

(3) When the car gets out of steering control, what should be done to bring it into control again?

(4) If the right wheels go off the pavement into a soft shoulder, what is likely to happen? What should be done?

(5) Assuming that the car is traveling at high speed on smooth pavement which suddenly changes to rough and threatens to put the car out of control, what is the proper thing to do?

(6) What should the driver do when a front tire goes flat?

(7) What should he do when a rear tire goes flat?

(8) What should the driver do when the rear wheels skid sidewise under power on wet or slippery pavement, on snow or ice?

(9) How should the driver handle the car when it sways from side to side on roads made of loose material such as gravel or slag?

(10) What is the proper manner of operating the car to slow it down or stop when going down a dangerous hill?

(11) What is the proper manner of operating the car on wet, slick pavement?

(12) What is the proper manner of operating the car on ice or snow?

(13) Should a car be handled differently down grade than on the level?

(14) Can brakes be used on curves in the same manner as on straight roads?

(15) Is it less dangerous to side-swipe another car than to take to the ditch?

(16) If a collision is unavoidable, what is the best course of action, if any?

(17) Should the clutch be engaged or not for emergency stops?

(18) On what occasions should the driver shift from high to a lower gear and how should it be done?

During the period in which I have had the preparation of this paper in hand, I have been in personal discussion and correspondence with many different automotive engineers, and while this has brought out the fact that car designers have individually given attention to various safety aspects of high-speed driving, many phases of this subject are still really very little understood. This is emphasized by the rather wide divergences of opinion on various matters and particularly each engineer's private views on the roadability characteristics of his car compared with other makes.

Roadability is a rather vague designation, but, nevertheless, under the scope of this heading must come some important characteristics relating to safety and handling a vehicle. Under this I would include such subdivisions as steering, effect of the height of the center of gravity, wheelbase length, geometrical relationship of axle and spring action and the way the car holds to the road.

Decelerability is a subject that is more or less self-explanatory and that subdivides primarily into the braking system as a whole, combined with the non-skid characteristics of the tires. The importance of a high coefficienct of friction between tires and road surface being so highly fundamental emphasizes the need for instituting some movement among Federal, State and County highway-building activities, a definite appreciation of the need for selecting road-surface materials that will give us a higher coefficient of friction. Further, they should strive to have this coefficient of friction more or less universal, so that no change will occur in passing from one strip of pavement to another. To illustrate this, I have noticed that the State or County will build a road and finish it with such a character of road surface that signs reading Very Slippery When Wet are incorporated as a part of the building program. Obviously, a situation like this sooner or later has to be corrected.

TABLE 1—DISTANCE AND TIME TO STOP A CAR

Road Surface	Rough Concrete		Firm Gravel		Wet Creosoted Wood Block	
Coefficient of Friction[a]	0.90		0.50		0.10	
Running Speed, M.P.H.	Ft.	Sec.	Ft.	Sec.	Ft.	Sec.
20	14.8	1.01	26.7	1.82	133.6	9.10
40	59.6	2.02	107.0	3.64	536.0	18.20
60	133.5	3.04	240.0	5.45	1,200.0	27.20
80	238.0	4.05	430.0	7.29	2,145.0	36.40

[a] For coefficient of friction as shown, all four wheels must be locked and sliding.

While this paper has dealt with the need for an understanding of the problem of controlling the car and educating the drivers, at the same time the question of whether the cars are inherently as safe as they should be, or whether by virtue of changes in design they can be made much safer, should be asked. Although I have picked up a smattering of information on this subject at different times, I know that I am not qualified to present the car-design phases of this subject. I am taking the liberty of mentioning the subject so that it can be treated at a future time by those people who are competent to handle it.

APPENDIX

We will be helped to visualize the complexity of the problem if we concisely list the various groups of weather, traffic, highway and automobile elements against the personal or human elements that combine in a multiplicity of ways to constitute the varying de-

grees of hazard. Expressed in a diagrammatic way, it would appear as follows:

$$\text{Driver} \left\{ \begin{array}{l} \text{Mentality} \\ \text{Emotions} \\ \text{Reactions} \end{array} \right. \begin{array}{c} \text{versus Combina-} \\ \text{tions of} \end{array} \left\{ \begin{array}{l} \text{Weather} \\ \text{Highway Conditions} \\ \text{Traffic} \\ \text{Car Characteristics} \\ \text{Human Reaction} \end{array} \right.$$

Each of these phases can be subdivided. The most prominent sub-classifications are as follows:

(1) Under weather we have
- (*a*) Darkness and fog
- (*b*) Rain, snow and ice
- (*c*) Wind and dust
- (*d*) Dirty windshield

(2) Traffic is mainly a question of
- (*a*) Density
- (*b*) Bright lights

(3) Highways are
- (*a*) Paved, gravel and unimproved
- (*b*) Crowned and flat, with and without ditches
- (*c*) Curved, banked or not. Banked on large or small radius of curvature
- (*d*) Narrow versus wide
- (*e*) Hills and grades
- (*f*) Side roads, intersections and drives
- (*g*) State of repair
- (*h*) Trucks, passenger-cars or motorcoaches

(4) The phases of automobile design are as follows:
- (*a*) Roadability
  - (1) Center of gravity
  - (2) Weight
  - (3) Steering
  - (4) Wheelbase
  - (5) Top speed
  - (6) Riding comfort
  - (7) Freedom from noises
- (*b*) Decelerability
  - (1) Brakes
  - (2) Non-skid tread of tires, new or worn
- (*c*) Mechanical condition
  - (1) Condition of tires to resist blow-out
  - (2) Gearshift
  - (3) Shimmy proof

(5) Of greatest importance are the extremes of reactions of the driver, both male and female
- (*a*) Impulse or instinct versus judgment based on knowledge or experience
- (*b*) Slow and sluggish versus quick and alert thinker
- (*c*) Panicky or excitable versus calm and collected
- (*d*) Reckless, taking chances versus cautious and careful
- (*e*) Tired and fatigued versus fresh and wide awake
- (*f*) Discourteous road hog versus gentlemanly and considerate
- (*g*) Inattentive versus concentrating on driving
- (*h*) Hot-headed versus even-tempered
- (*i*) Likes thrills versus fear
- (*j*) Sober or otherwise

THE DISCUSSION

CHAIRMAN WALTER C. KEYS[2]:—The attitude of the motoring public today, so far as speed is concerned, I believe can be summed up this way; first of all give us safety; second, comfort and third, speed. As soon as vehicles and highways permit safe and comfortable travel at 100 m.p.h., we will drive that fast. Then will come speeds of 150 m.p.h. and so on. Some power-plants of today's motorcars are good for 100 m.p.h., but as yet we have very few roads on which a distance of 50 miles can be traveled at a sustained speed of 70 m.p.h. Based on the present rate of increase in speed, rates of 500 or 1000 m.p.h., which our descendants will realize under controlled conditions, do not seem impossible.

We hope that every useful, practical suggestion and experience related here tonight will be given wide publicity in the hope that *some collisions* and *some loss of life* may be prevented somewhere in this broad land of ours.

DR. H. C. DICKINSON[3]:—In the first place I cannot entirely agree as to the distinction between high-speed driving and driving at more moderate speeds. The differences between the technique required at any speed above 20 m.p.h. and the highest speed appears to be entirely a matter of degree and not of kind. Of course, for the purposes of the paper, limiting the discussion to speeds above 60 m.p.h. is wholly justifiable for practical reasons, if not for analytical ones.

Essentially, the only two methods of meeting any emergency are to stop or to dodge. The technique required for either procedure or the combination of the two necessarily depends almost entirely upon the local conditions as regards possible brake action and control of the steering, including selection of a place into which to steer. On the problem of steering, I shall add some more pertinent comments later.

Action in Various Emergencies

When descending a hill with improperly banked curves in the middle of the grade at too high speed unless one can steer off the road without a wreck, the only alternative appears to be to use the brakes at the best possible efficiency before reaching the curve. If the speed down a hill is excessive and the pavement is slippery but the road is reasonably straight and clear, the safest course is to coast and in extreme cases de-clutch. If curves cannot be made at speed without skidding, probably the only alternative is to steer into soft ground or into any type of obstruction which can be used to slow the car without catastrophe. With four-wheel brakes very careful intermittent application of brakes may be employed, preferably with the clutch out, when descending too rapidly a hill having a road surface composed of loose material.

Action, when crowded off the pavement by another car, will depend almost entirely on the nature of the road shoulder and adjacent terrain. In extreme cases when crowded on a dangerous road shoulder, steer against the crowding car. Such action may prevent being crowded over a bank at the expense of minor injury to the vehicles. When another car crosses in front of one's car, the only possible course is either to stop or to find a safe path into which the car can be steered. Steering out of the way is usually the only possible way when approaching a car on the wrong side of the road, on the crown of a hill or around a blind curve. The possibility and safety of such a maneuver will depend absolutely on the highway terrain and traffic conditions. When meeting pedestrians on a

[2] M.S.A.E.—Sales engineer, Detroit.

[3] M.S.A.E.—Chief of the heat and power division, Bureau of Standards, City of Washington.

highway, the first requirement will be to avoid hitting them. In many cases careful steering will be the only remedy and this again depends entirely upon the terrain.

Blowing out of a front tire leaves no alternative but to hold the car in the road if possible. The use of either two-wheel or four-wheel brakes is dangerous. The rear-tire blow-out at high speed is probably more difficult to handle than a front-tire blow-out. Application of four-wheel brakes is about as dangerous as in the previous case. Two-wheel brakes must not be used. Breakage of the steering-gear leaves nothing available but the brakes which might be used provided the car stays in the road. Failure of the propelling mechanism seems to present no special hazard, provided the steering and braking mechanisms are available.

Slippery pavements involve only the careful and skillful use of the brakes under various conditions that are discussed subsequently, except for the difference between muddy roads and snow or ice. Brakes may be used with care and moderation in the case of water or mud, whereas, with snow and ice, to avoid breaking the contact of the tire and the road is of utmost importance.

In the case of ruts the only safe procedure at high speed seems to be to cross the ruts at a sufficient angle to prevent dropping into them. Otherwise, the car may go entirely out of control. Ridges of loose material should never be crossed at high speed if this can possibly be avoided. If such crossings are necessary, they can probably be made more safely with clutch out or with the throttle open to such point as will mostly relieve the torque on the rear wheels. Four-wheel brakes can be used moderately on a bumpy road, otherwise the only course seems to be careful steering and dodging where possible.

Application of Brakes

Four-wheel brakes are much more complicated to use, although much safer, than two-wheel because the performance depends entirely upon which wheels begin to slide first. In general, a skid at any time at high speed is dangerous because the car may quickly get out of control; also because, on some classes of road, the rolling friction is much greater than sliding friction. This is particularly true on ice and snow where a slide once started is difficult to stop.

On a normal road and in the hands of a very skillful driver the maximum decelerating effect can certainly be obtained by applying the brakes to a point where skidding is just avoided. However, as this requires more than human skill, the maximum deceleration will probably be obtained by most drivers by applying the brakes with gradually increasing pressure until an indication of sliding wheels or lack of control is apparent, then releasing the brakes momentarily to allow the wheels to grip the road again. This performance can be handled most safely with the clutch out since when the brakes are released the rear wheels, having no torque applied to them, will more quickly grip the road.

I have no clear-cut way of telling when the wheels begin to slide, except by feeling of instability of the car and in some cases by the sound. In applying the brakes I rely mainly upon judgment as to what any particular road-surface will permit and in driving on wet, slippery or unfamiliar roads I often test the brakes at moderate speeds to judge more accurately the safe degree for braking pressure at high speed.

Steering is, I believe, the most important element in safety for high-speed traffic, and the one element that has been given practically no scientific consideration in the design of present-day high-speed motor-cars. As a matter of fact, steering-gears are at present designed for *parking* cars and not driving them. A very interesting article in *Automobile Engineer*[4] gives some very pertinent suggestions on steering, brakes and other subjects. Among other things this article analyzes the performance of the car with the rear wheels sliding.

Sliding and Skidding

If the rear wheels are caused to slide either by application of the brakes or by over-application of power, the tendency of the car is to turn end for end and the angular velocity at which the turn is made increases rapidly as the turn progresses. To correct such a skid, the only alternative is to counteract the angular motion of the car by a corresponding setting of the steering-wheels. The possibility of making this correction will depend upon the relationship between the relative angular acceleration caused by the skid and the angular acceleration that the driver can impart to the wheels through the steering mechanism. The latter, in turn, depends upon the angle through which the driver must move his hands and the time required for his reaction and that of the vehicle. Obviously, therefore, a steering-gear with too high a reduction, which is requiring too great an angular motion of the steering-wheel, cannot be controlled in the case of skidding under as severe conditions as a vehicle with a lower steering reduction. In other words, the high-speed vehicle needs a lower steering-gear ratio than the low-speed vehicle.

While the correction of skidding is not as important as it was in the days of two-wheel brakes, it is still important with modern cars because of the danger of power skids under unfavorable road-conditions. However, a still more important element in safe travel at high speeds is the ability to steer accurately and quickly into any available space in case of an emergency. The present-day high steering-gear reductions, coupled in many cases with a certain elastic flexibility in a steering mechanism which introduces a time lag, seriously impairs the ability to steer accurately in emergencies. So important is this element that I believe builders of high-speed cars should be induced to make a very careful study of the problem not only from the theoretical but particularly from the experimental standpoint.

If a car goes out of control, two things should be done; (*a*) relieve all torque on the wheels by releasing both brake and clutch and (*b*) counteract any angular motion of the car, if possible, by a counter-motion of the front wheels. However, if a skid has reached an unmanageable stage, counteracting the angular motion of the vehicle may not be possible, in which case an attempt should be made to place the front wheels parallel with the direction of the front end of the car. This maneuver will enable these wheels to grip the pavement, after which they can be used to overcome the angular motion.

Applying brakes will put the car further out of control; that is, with the brakes applied, the car will slide with no directive effect whatever. When the back end of the car becomes unstable and tends to walk, torque on the rear wheels should be relieved. Whether this can be done best by closing the throttle to the proper point or by releasing the clutch will depend upon the conditions and the skill of the driver.

Danger from Blow-Outs Exaggerated

B. J. Lemon[5]:—A rather interesting article by the British National Physical Laboratory on the effect of skidding on different road surfaces was recently published[6]. This gives considerable useful information that while perhaps not entirely applicable to heavy cars but more to the lighter types of car yet is informative on the effect of side or radial skidding of different tire designs on different road surfaces, both wet and dry.

[4] See *Automobile Engineer*, January, 1930, p. 21.

[5] M.S.A.E.—Field engineer, tire development division, United States Rubber Co., Detroit.

[6] See *Automobile Engineer*, February, 1931, p. 73.

Recently I witnessed some tests that were made to see what the effect would be of instantaneous blow-outs at 65 and 70 m.p.h. The surprising result was that no appreciable difficulty was experienced in controlling the car at those speeds. A front-tire blow-out appeared to give less trouble than a rear tire, because we have control of the front wheels when the tire blows out. While a certain pull occurs to the side where the tire blows, the rear-end sway that we have when a rear tire blows out is absent. The ordinary tire does not blow out instantaneously unless the casing is very old. Instead the air goes down rather slowly with a tube leak, and even with a puncture the air goes out very slowly, so that a driver who has ever driven a flat tire should know when the air is gradually leaking out. In a high wind, of course, the effect on the car is about the same as with the leaky tire; that is, we get a sway particularly if a rear tire is at fault, and if we pay no attention to it as in a high wind, the tire may go almost entirely flat before we begin to check the car. From the experiences I have had and the tests I have witnessed, I believe the danger of a tire going flat is not as great as most people think.

Study of Accident Causes

DAVID BEECROFT[7]:—Very broad studies of accidents have brought out the fact that 80 per cent of the highway accidents last year were entirely due to the personal factor and not to the vehicle, also that 80 per cent of the accidents occurred on good highways, and that 80 per cent of these accidents occurred in clear weather. In other words, our major percentage of accidents take place under favorable conditions. Very broad studies of drivers are being made at present in several States to determine if some final conclusion can be reached as to why so many of our accidents take place.

I would like to confirm what Mr. Lemon said. I have driven cars when the rear tire has blown out at a speed of 77 m.p.h. In such a case we must not put on the brake; that is all. The car will go straight ahead.

That a great many human beings get into a somewhat deranged state of mind and also into a deranged state physically has been established in studies made in Pennsylvania. Where the food of drivers has been taken into consideration over a period of three months, those drivers have been brought out of a state of mental uncertainty, a state of physical uncertainty, back into a state of complete poise and reliability.

Unquestionably a great many of our accidents are due to physical and mental fatigue. That is proved by the fact that the majority of our accidents take place between three o'clock in the afternoon and seven in the evening, times naturally when people are more fatigued. Traffic studies show that the traffic is not perceptibly greater than it is in the morning hours from 7:30 until 10 or 11, when the accident total is very low.

We have very definitely reduced the number of highway accidents to school children in the last year and a half, although the total of all accidents in the Country has been increased. That has been due to the fact that in our schools, where safety campaigns have been carried on, studies of specific accidents have been made. They have been analyzed for the children, and by virtue of that analysis the children have a broader knowledge of safety.

The other controlled group is that of taxicabs and large operators of fleets of trucks and motorcoaches. Here a definite reduction of the number of accidents has been made. Accidents have increased with the great masses of individual owners, many of whom have never had an accident until the first one happened which may have been more or less serious.

We have tried to launch a program this year by which our daily papers would carry a small box, similar to the golf lesson, that would be a study of the cause of an accident. We believe that by virtue of a broad educational program of this nature, we would add very much to our safety.

Unquestionably we shall increase our speeds. All of our highway departments are arranging our highways with that point of view. If we are to attain the safety factor that we should have, we must work with the human beings. That is where the remedy lies.

W. S. JAMES[8]:—When we are driving a car that weighs 4000 or 5000 lb. on the road, we must know what to do with it. The time to think is not then, but the year before. Everyone should give very serious consideration to the questions that Mr. Hale has propounded. I do not pretend to be able to answer all of them correctly. We certainly should hold on to the steering-wheel regardless of what happens because we usually can rely on the steering-gear following our desires. If we get into a jam and put the brakes on too suddenly, we are likely to steer from the rear wheels instead of the front, which is very disconcerting. If, however, we hold on to the steering-wheel, we have a chance to go between two trees rather than climb one of them.

Steering Mechanism Needs Attention

Automotive engineers should give very serious consideration to the details of the steering mechanism, not only to the steering-gear itself but also to the geometry of the steering knuckle, the drag linkage and the whole braking and steering system because we should be able to drive a car at the top speed that it will go, and handle it with perfect ease. That is not very easy because, with present spring-suspensions, the wheelbase on the right and on the left sides of the car may differ by 2 in. In other words, with spring action, the angle of the front axle in reference to the rear axle may assume very significant proportions. As a result the steering-gear should be laid out so that it will inherently correct the variation in the wheelbase, and on a rough pavement the car will move straight instead of veering either to right or left. This change in wheelbase differs somewhat when the front springs are shackled at the front instead of the rear. In fact, the difference in the change of wheelbase with front shackling is about twice that with rear shackling. Therefore, the correct geometry of the car must be thrown off to compensate.

Constant attention on the part of the driver can reduce accidents more than almost anything else. When driving a heavy vehicle we are taking in our hands not only our own life but also the lives of the passengers. That requires 100 per cent of our attention.

A Racing-Car Designer's Views

FRED S. DUESENBERG[9]:—Some cars are entirely safe at 80 m.p.h., while others are not safe at 50. On the whole, safe driving depends largely on the man who is sitting at the wheel and what the car will do. Many cars that have not sufficient power and acceleration cause accidents on the road while other cars that do have plenty of speed, accelerate rapidly and kick up dust are not nearly so dangerous as some that cannot be driven at speeds beyond 50 m.p.h.

I have had considerable experience in the last few years in driving our own cars at high speed. I always feel that we stay on the road very nicely, but every once in a while somebody gets in our way, or does something that he should not do, and at times that is dan-

[7] M.S.A.E.—New York office manager, Bendix Aviation Corp., New York City.

[8] M.S.A.E.—Research engineer, Studebaker Corp., South Bend, Ind.

[9] M.S.A.E.—Vice-president in charge of engineering, Duesenberg, Inc., Indianapolis.

gerous. If a car is built so that it does not have too much sway and accelerates quickly, that car is safe under almost all conditions. If someone gets in front of it on the wrong side of the road or when we are coming up a hill or going around a curve, then it is just too bad if we are going too fast.

Brakes are the most essential things for high-speed driving, and brakes that are too severe are very dangerous. If brakes were made so that the first application is rather gradual, high-speed driving is safe, but if we once start locking a wheel, particularly on turns and when we are trying to get out of somebody's way, that is very dangerous. After dark is when I have most of my trouble. Somebody is coming toward me and swings over too far on my side of the road, and I have to swing out a little bit, and if I am going 100 m.p.h., it is hard to tell where I am and it is too bad if I run off the road.

The greatest danger that I see in high-speed driving is the unexpected road-conditions. When any element of danger is present, the only course is to go slowly. Nothing can take the place of careful driving and using good judgment. Many people who use good judgment are as safe at 75 m.p.h. as the average drivers are at 50. We should not try to hold the car speed down, but should speed up the slow cars and thus make the road much safer than would be the case if the fast cars were compelled to run more slowly.

Only Competent Drivers Should Drive Fast

G. C. BROWN[10]:—Driving a car at high speed is very similar to flying an airplane. Experience with the airplane has proved that not everybody can fly one; very many persons are temperamentally unfitted for it. High-speed driving should be confined to those who can handle cars capably at high speeds. At the Indianapolis races only those who have proved their ability are permitted to drive. This makes apparent the human factor, and how that is to be controlled is beyond me. This is what is commonly termed a free country, and everybody will insist on his right to do what anybody else does. To place an 80-m.p.h. car in everybody's hands is not safe.

A short time ago I drove a car at 82 m.p.h. Those 5280-ft. miles shrunk to Austin size very quickly. I rarely indulge in high-speed driving, because I see frequently the effects of what other drivers do. When I see a car coming toward me at high speed, I give it all the room possible, because I do not know if the driver is capable of handling that car at high speed.

We have no highways that are properly constructed for high-speed driving. Sometime ago I understood a road was under consideration in California which was to extend from Los Angeles to San Francisco and was to have several lanes, one of which was for high-speed operation with a minimum speed of 60 m.p.h. Anyone in that lane traveling less than 60 m.p.h. would be given a ticket. That road has not materialized to date.

Some of the cars of today are reasonably safe for high-speed operation. Some drivers are competent to handle them. The matter is one in which the human factor figures largely. The car of itself can not assist in the control. We must educate the driver, and to do this, we have a difficult problem.

HAROLD NUTT[11]:—We scratch our finger and it hurts, and the next time we are careful. It is the same with driving a car. If we cover any miles at all, we may have one or two close calls. If we have many of them, we should change our habits. Each minor accident or narrow escape is a definite warning, a danger signal.

On the other hand if a man can drive for 20 years and have no close calls, he a good driver and will probably never get into a serious accident. If we will watch our habits in traffic we can tell whether we are safe drivers at any particular speeds or in various kinds of traffic. Look over the past. Go out and examine the old car. See how the fenders appear. If they are much damaged you had better slow down or else leave the car in the garage.

HERBERT CHASE[12]:—A report that was recently issued by the Travelers Insurance Co. which was an analysis of the accidents that occurred in the last calendar year showed that something over 16 per cent of the accidents occurred through driving on the wrong side of the road. Over 3200 persons were killed and over 100,000 injured in 1930 because of this fault in driving alone. Almost anybody knows that he ought not to drive on the wrong side of the road, and yet many high-speed drivers do it, as do also many others who consider themselves careful.

I feel that we cannot stress too much the need for keeping on the right side of the road if we intend to drive fast. To be relatively safe, no one should drive at such a speed that he cannot stop within the distance that he can see to be clear ahead. This may seem a little conservative, but nobody can, for example, drive around a curve at 75 m.p.h. safely, unless the view of the road ahead is unobstructed. Guessing or taking for granted that we have a clear right-of-way when we cannot see it is not wise.

Suggested Changes in Cars

A MEMBER:—The human element of this dual arrangement of driver and car is being somewhat overemphasized and I want to suggest certain things that might be done to improve the vehicle. Brakes have been brought to our attention, and, of course, their function is to take care of the weight. If we had not reduced the weight in airplanes any more than the automobile industry has been able to do in automobiles up to this time, we would not be flying at all. Lessons can be learned from airplane construction which would allow us to lighten the cars very much and naturally that would double the efficiency of our brakes. Lowering the center of gravity is being done gradually, but many things could be done to help that situation.

In the early days of the airplane we tried steel springs. These bounced the airplane around so badly that securing an even flow of air over the top of the airplane was impossible, and without that even flow it will not rise. Nearly all airplane constructors tried both coil and leaf springs and found them wanting. Another method of suspending airplanes has been developed until it is very superior, in my opinion, to steel springs; it is the use of rubber and the oleo gear. If those lessons could be applied, that might do considerable toward improving the vehicle.

The steering-gear naturally is of the greatest possible consequence to safety. Yet the steering tie-rod is located down under the car, the part of the car nearest to stones and rocks and supposed to be hidden by the front axle. If at any of these high speeds that we have been talking about we hit a rock or stone, that might easily cause an accident. Another thing is the little, delicate brake-seating mechanisms that we find within 6 or 7 in. of the ground.

MURRAY FAHNESTOCK[13]:—The point has been brought up that our steering-gears are designed for parking rather than steering at high speed. For parking with balloon tires we necessarily need a steering-gear ratio of 15, 18 or 20:1. For steering at high speeds we may need a ratio of 8:1 or something like that. To overcome

(Concluded on p. 405)

[10] M.S.A.E.—Sales engineer, aircraft division, Bohn Aluminum & Brass Corp., Detroit.

[11] M.S.A.E.—Director of engineering, Borg & Beck Co. division of the Borg-Warner Corp., Chicago.

[12] M.S.A.E.—Consulting engineer, New York City.

[13] M.S.A.E.—Technical editor, *Ford Dealer & Service Field*, Pittsburgh.

Carburizing with Gas in an Electric Furnace

By H. E. Koch[1] *Milwaukee Section Production Meeting Paper*

NITRIDING sometimes demands a furnace which cannot be kept employed all the time. It also stimulates the development of carburizing processes. A furnace is described which can be used for both nitriding with ammonia and carburizing with either city gas or gas produced by vaporizing a specially blended compound. Carburizing costs by this method and by the electric box-furnace method are tabulated for comparison. Relatively low first cost and operating cost and a high degree of flexibility are claimed for the equipment.

Discussion has to do with difficulties with alloys in high-temperature equipment, the effects of diffusion treatment, methods of packing work to secure uniform treatment, and protection of local surfaces which should not be case-hardened.

NITRIDING furnaces of a certain size often are needed for some specific machine part in an establishment which has not enough nitriding work to keep the furnace busy. The introduction of Nitralloy products also has placed upon the carburizing art the burden of improving its quality and reducing the cost of operation.

Recent activity in carburizing in a gaseous atmosphere is such as to create the impression that it is a new art. Although it is relatively new in its commercial acceptance, its history extends back to the middle of the 19th century. The problem then was to produce steel from wrought iron, and many designs of furnace were proposed for cementing armor-plate.

The electrically heated gas carburizer is a fairly recent development which possesses the accuracy and ease of temperature control that characterize well-designed electric furnaces. The vertical carburizer introduces an entirely new factor in the use of forcibly directed circulation of the carburizing gas. It shows unusual results and introduces a new conception of the principles of gas carburization. One of the smaller furnaces used in this service is shown partly in section in Fig. 1. The heating elements are arranged to give one, two or three independently controlled zones, according to the depth of the furnace. Inside the furnace chamber is the carburizing container, or retort, which is closed gas-tight at the top by an insulated plug-type cover on which is mounted a motor-driven fan mechanism. Tightly sealed inlet, outlet and test-thermocouple pipes are provided in the cover. The fan is centrifugal, having a center suction and lateral discharge. A curved deflector-plate guides the discharged gases downward along the hot side-walls of the retort.

Inside the retort is a work-holding basket which has holes for the entry of the hot gases at the side as well as at the bottom, the arrangement of the holes depending somewhat upon the type of carburizing gas to be used. Usually the work is merely shovelled into the basket; it is not necessary to load it as in the ordinary carburizing container. Too much weight should not be placed on the lower part of the charge, as it may cause distortion under heat. Shelves can be used to distribute the weight and separate the bulk; and fixtures can be made for special applications, particularly for the larger individual pieces.

Operation of Gas Carburizer

The cycle of operation is as follows:

(1) The basket is loaded with work and placed in the retort and the cover is bolted in place.

(2) The charge is brought up to the carburizing temperature that the job requires, which may be from 1650 to 1800 deg. fahr.

(3) The gas or gas-forming liquid is turned on and the charge is held at heat for the required time.

(4) After the carburizing fluid has been turned off, the charge may be held at heat to permit the case to diffuse.

(5) The entire retort assembly can be lifted out of the furnace to take the work through a controlled cooling cycle, or the basket alone can be transferred to a cooling chamber, or the work can be quenched from either the carburizing temperature or from some lower quenching temperature that is specified. This completes the cycle.

The fan performs four functions. First, it helps to transfer heat from inside the retort wall to the charge, bringing the charge to heat more quickly; second, it distributes the incoming gas uniformly throughout the annular chamber between the retort and the basket; third, it imparts velocity to the gases while they are being heated and conditioned for carburizing; and, fourth, it causes a turbulent flow of gas inside the basket.

Free flow of gas over the work is not wanted. A certain amount of molecular collision takes place in a heated gas. If this collision effect is minimized while the gas is being heated and the hot gas is distributed during its flow through the charge, a very active and violent effect is produced around the work that is being carburized. Producing this turbulence around the work is the principal function of the fan.

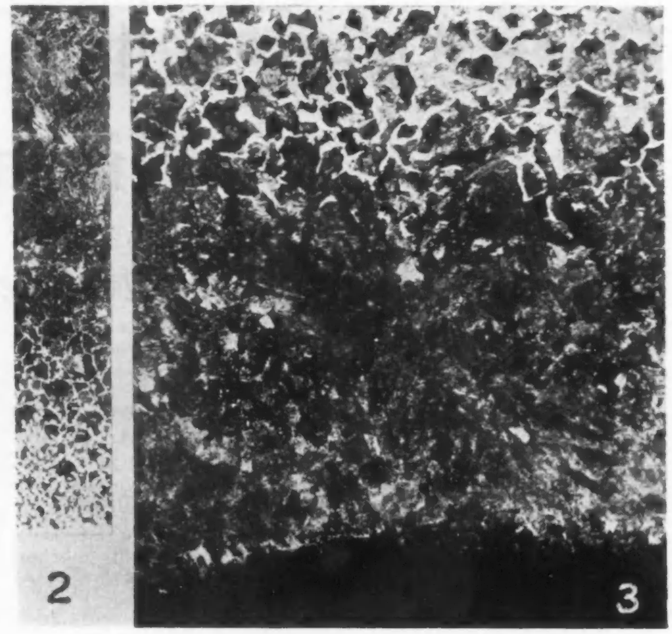
[1] Research engineer, Hevi-Duty Electric Co., Milwaukee.

Chemical Mixture Produces Suitable Gas

City gases available in many sections of the Country are good for carburizing, certain kinds of natural gas in particular; however, each locality presents its own problem. Moreover, the public utility company which supplies the gas usually is limited only as to the heat content, hence the chemical composition may vary enough to seriously derange the whole carburizing operation.

For this reason, the company with which I am connected has developed a chemical mixture, called Carbonal, which is blended to vaporize into a gas that will produce uniform results wherever the furnace is used. In this way the purchaser is assured of the results he can obtain. He may decide to operate his furnace on local gas and obtain excellent results therewith, but the chemical mixture offers a definite way out in case of trouble.

A tendency has been noticed during the last few years to specify not only the depth of case but the nature of the case structure itself as to carbon concentration and gradation. Fig. 2 shows a typical case structure having hypereutectoid network structure at the top, eutectoid in the dark center and hypoeutectoid in the gradation zone lying between the center and the core. Carburizing specifications today give the amount of each of the three classes desired in the carburized piece. In many cases, only eutectoid and hypoeutectoid areas are permitted, the hypereutectoid zone being diffused to the eutectoid structure by holding the charge at heat without supplying carburizing gas, thus allowing some of the carbon in the outer structure to penetrate further, as shown in Fig. 3.



CARBURIZED CASE STRUCTURES (MAGNIFICATION 100 TIMES)
Fig. 2—Typical Case Showing Three Zones
Fig. 3—Case in Which Carbon Has Been Diffused by Prolonged Heat

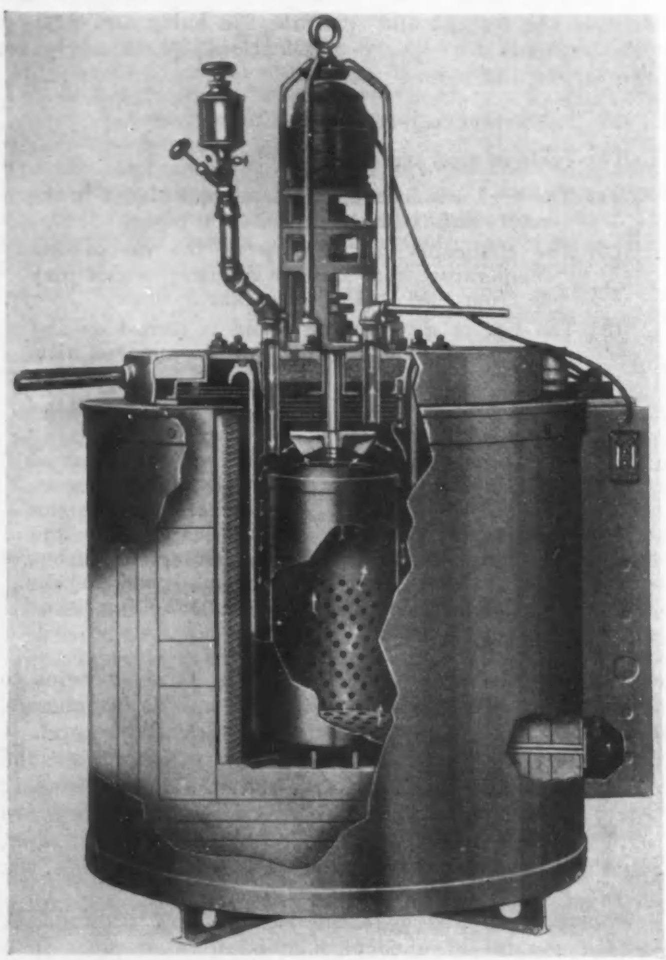


FIG. 1—FURNACE ADAPTED FOR GAS CARBURIZING

Based on the Design of a Vertical Electric Nitriding Furnace, This Unit Is Adaptable for Either Nitriding, Carburizing with City Gas or Carburizing with a Liquid Compound Which Becomes a Gas in the Furnace. The Feed-Cup Beside the Motor Which Drives the Circulating Fan Is for the Carburizing Fluid

This carburizing process has flexibility to control case structures to meet the needs of increasingly rigid carburizing specifications. The construction and the accurate temperature control of the furnace assure uniformity of temperature from top to bottom. Many tests of samples from all parts of representative charges show a uniformity of structure within limits formerly unheard of in carburizing.

Penetration of S.A.E. No. 1020 normal steel usually proceeds at the rate of 0.012 to 0.015 in. per hr. when the charge is at 1700 deg. fahr., so a 1/16-in. case would require 4 to 5 hr., depending to some extent upon whether the stock was cold-worked, forged or hot-rolled. Pearlitic manganese steels designed particularly for carburizing show penetration from 0.015 to 0.018 in. per hr., according to the steel chosen and its surface condition. The rate of penetration for most steels falls off slightly as the case becomes deeper, but the case shown in Fig. 2 was produced to a depth of 5/32 in. in 10 hr. at heat.

The resulting shortness of the carburizing cycle has many industrial advantages, and the production of carburized material per dollar invested in furnace equipment is very high. Material can be passed through the heat-treating department more rapidly and the power consumption is reduced greatly because of the shorter time and reduced radiation. In many instances a vertical gas carburizer can turn out as much carburized material with a given amount of electrical energy as can a box-type furnace, without recuperation, powered four times as high.

Costs by Different Methods Compared

Cost analyses of carburizing both with the vertical electric carburizer using Carbonal and with the older style of electric box-type furnace handling packed boxes will be of interest. The cost of oil-carburizing equipment having a capacity of 800 pieces of a total weight of 1200 lb. per day is $2,004 for the furnace and $150 for the fixtures; making a total of $2,154. The cost of the box-carburizing furnace having the same daily capacity is $3,500; and 3/8-in.-thick boxes, 14 x 8 x 14 in., sufficient for continuous operation, cost $3,164, making a total of $6,664. The fixture for gas carburizing weighs 75 lb., the charge is 100 pieces, making a total weight of 225 lb. per charge, and 8 heats are handled per day. Alloy consumption in the vertical furnace is based on a guarantee of 5000 hr. of service and a metal cost of $1 per lb. Boxes holding 24 pieces for the older type of furnace weigh 115 lb. each, 14 boxes are used per heat, and 2½ heats can be run in 24 hr. Total electricity for heat and radiation, including 20 per cent miscellaneous losses, is 40 kw-hr. per heat for the oil-carburizing furnace and 317 kw-hr. for the box-carburizing. At 2 cents per kilowatt-hour, the current cost is therefore 80 cents per heat, or $6.40 per day, for oil carburizing and $6.54 per heat, or $15.85 per day, for box carburizing. A summary of costs is given for comparison in Table 1.

The figures given do not include labor cost, as that varies in accordance with conditions at the plant. The labor of packing boxes with parts and compound and loading and unloading of boxes into and out of the furnace is eliminated with the retort method, as the parts are loaded in light racks and placed in the furnace in one batch with an electric or air hoist.

TABLE 1—DAILY COST OF CARBURIZING 1200 LB. PER DAY BY TWO METHODS

	Oil Carburizing	Box Carburizing
Electricity	$6.40	$15.85
Carburizing Material	1.12	2.64
Alloy Consumed in Retort, Fixture and Boxes	1.44	7.58
Depreciation of Furnace at 20 Per Cent	1.19	2.33
Total Cost per Day	$10.15	$28.40
Total Cost per Pound	$0.0084	$0.0236

No data are given regarding cost with the recuperative counterflow type of continuous furnace, because of the variations in economy obtained on each production job with a furnace of this type. However, we have found repeatedly that a battery of vertical furnaces in which the loading is done by suitable crane equipment and provision is made to recuperate heat from retorts which are cooling down will merit consideration for economy alone, without taking into account the increased flexibility and lower inventory.

Carburizing with gas or liquid possesses also certain intangible advantages, principal among which is the fact that the heat-treating department can be kept clean. Dust and dirt from carburizing compound have been very discouraging in this respect.

The electric vertical carburizer is an advance in electric heat applications because it adds a little more science to the carburizing operation, gives a large output in proportion to the investment, and makes possible the doing of small carburizing jobs on a cost basis that is competitive with that of large-production furnaces.

THE DISCUSSION

JOSEPH GESCHELIN[2]:—I have noticed that replacement of retorts seems to be quite a problem in several of the plants I have visited. Has anything been done recently to increase their life?

H. E. KOCH:—The application of high-grade alloys for high-temperature equipment is relatively new. Large retorts are lifted out of the furnace at a temperature of about 1700 deg. fahr. and cooled rapidly, often with the aid of a fan to obtain a modified normalizing effect. However, we have been able to trace most of the difficulty experienced with retorts to foundry conditions, and changes in design and methods of handling have eliminated most of the trouble. The same sort of trouble has occurred with carburizing boxes, many of which crack in the furnace because they were not properly cast.

W. E. RUTZ[3]:—Is there any limit to the depth of a vertical furnace; and can the electrical units be adjusted so that a furnace can nitride long pieces at one time and short pieces at another?

MR. KOCH:—The furnace can be built as deep as you are likely to want. Some provision might have to be made in the fan, fixture or basket to cause uniform circulation. The furnace can be built seven or eight zones, or 40 ft., high with no great difficulty.

MR. RUTZ:—I was considering lengths of 16 to 18 ft.

MR. KOCH:—That would cause no problem in nitriding except in the manner of holding the work, but for carburizing we would give attention to the problem of properly distributing the gas.

Diffusion Heat Extends Uniform Hardness

H. MUCKS[4]:—How does the use of Carbonal affect the hardness of the different zones of carburized work after hardening?

MR. KOCH:—If the core is heat-treated and the case is hardened properly at low temperature, to bring out the fine grain in the case, the hardness from carburizing is about the same as that from nitriding. A Brinell reading of 950 can be secured about as easily with carburizing as with nitriding, but not much higher readings can be obtained in the eutectoid structure.

MR. MUCKS:—If the hypereutectoid layer is removed, how hard will the next layer be?

MR. KOCH:—It would still be about 925 Brinell or 65 to 67 Rockwell. Ferrite causes soft spots as soon as the third layer or gradation zone is reached; that is why the diffusion cycle is used, to extend the eutectoid structure by diffusing.

MR. MUCKS:—Will diffusion have the same effect in nitriding? (*Concluded on p.* 405)

[2] M. S. A. E.—Associate engineering editor, *Automotive Industries*, Chilton Class Journal Co., Philadelphia.

[3] Superintendent, Giddings & Lewis Machine Tool Co., Fond-du-Lac, Wis.

[4] Superintendent of heat-treating and forge shop, Highway Trailer Co., Edgerton, Wis.

Design Problems of the Autogiro

19th National Aeronautic Meeting Paper By W. Laurence LePage[1]

SOME OF THE PROBLEMS that confront the designer who starts out to produce an Autogiro are analyzed. These include static and dynamic balance, control of the machine in flight and descent, control of the rotor speed and of the oscillation of the rotor blades, design of a suitable landing-gear, relation of rotor diameter to rate and angle of climb, and effect of weight on flight characteristics.

Discussers raise numerous questions regarding performance characteristics that elicit interesting additional information bearing on ability to take off from water, gliding angle, rotor behavior under conditions of inverted loading, effect of increased disc loading on rate of descent, attitude of the machine at gliding angles, reason for choice of four rotor blades rather than more and a smaller disc-diameter, utility of free-flight tests with models of moderate size, size limit and load-carrying capacity of the Autogiro, practical field of application, relation of landing speed to level-flight speed, best location of center of gravity, inability to stall the fixed wing, and absorption of inertia effects of the rotor-blades and side thrust when landing.

WE ARE INCLINED to look upon so-called new ideas in aeronautics as necessarily involving new fundamentals, but I should like to have you regard the Autogiro and its theory as nothing distinctly new fundamentally; rather, as new only in the application of long-proved basic fundamentals. With that as the datum line, as it were, we place ourselves in a mental attitude which unfolds the picture of the theory and development of the machine as far less mystic and more practical than we might otherwise believe it to be.

The theory of autogyration has been expounded[2] before the Society and need not be elaborated upon at this time. It involves the harnessing of the resultant force of the air loads acting upon a series of airfoils pivoted radially and free to rotate under the forward slope of this resultant force as it applies to each blade and in relation to the common axis of rotation. This causes rotation, and the motion is both steady and stable.

The theory is necessarily much more complex than this brief statement would indicate; in fact, it is so complex that it has not yet been fully propounded. Mr. Cierva, the inventor of the Autogiro, has prepared a very complete discussion and mathematical analysis of all the conditions, within certain limits, under which the machine functions. This theory is the basis of the design today and will continue to be the foundation upon which development and additions will be made.

I should like to analyze some of the problems that present themselves to a designer starting out to produce an Autogiro. Probably the most important is that of balance. Unlike any other aircraft structure, an Autogiro demands two distinct conditions of balance; one, dynamic balance, and the other, static balance.

Securing Dynamic and Static Balance

Dynamic balance is probably the easier to acquire, because ways and means of securing dynamic balance already have been developed. These may be complicated but they are not new and their application is more or less well understood. In general, they involve the correct choice of area and location of the tail; the location of the center of pressure for the wings; and correct choice of the relative locations of the major component parts of the airplane which contribute to its weight, with the idea of determining the appropriate position of the center of the gravity for the entire ship.

Static balance calls for a quite different type of analysis. In an Autogiro designed to have adequate dynamic balance only, the major characteristic, namely, its ability to descend vertically, would be lost. Under conditions of vertical or nearly vertical descent, the effectiveness of the tail surfaces is greatly reduced if not entirely lost owing to the great reduction of relative air velocity. Thus dynamic balance is greatly re-

[1] M.S.A.E.—Chief engineer, Kellett Aircraft Corp., Philadelphia.

[2] See S.A.E. JOURNAL, September, 1930, p. 257.

duced and a very definite degree of static balance is requisite. Therefore, one faces the difficult problem of building a plane that will not only satisfy the requirements of dynamic balance but will also balance in vertical descent as a parachute.

Dynamic balance is obtained with the aid of tail surfaces, other things being equal, but, because the resultant lift force of the rotor is nearly always passing through or very near the true axis of rotation, that is, the hub, forces on the tail surfaces would be expected to remain similar for all speeds over the range of flight.

This, however, is not true. The machine is affected by a change of balance, due to change of speed, that is similar though not equal to that characteristic of the airplane; but it results, not from a center-of-pressure movement, but from the flapping of the rotor blades as they pass around the cycle. The blades rise and fall about the horizontal articulations as they rotate, and this flapping motion equalizes the lift forces on the two sides of the cycle when the machine is in forward motion. The greater the speed of translation is, the greater is the degree of flapping for a given rotor speed; and this flapping motion, superimposed upon the rotational motion of each blade, results in the phenomenon of tilting the conical locus of the blades as they turn.

Rotor Inertia and High Center of Gravity

It is necessary, however, to introduce another influence, namely, that of inertia, which results in delaying the phase angle of the flapping so that, instead of being maximum at the laterally disposed points, it has its maximum positive value at a point approximately 120 deg. later, that is, ahead and slightly to the left of the longitudinal axis of the machine. Accordingly, the "cone" is tilted backward and slightly to the right instead of laterally to the left, as is indicated by the theory, neglecting inertia. Since the lift vector always bisects the "cone" of the rotor and passes approximately through the hub, it, too, is tilted backward but slightly to the right under the influence of flapping.

Imagine the resultant force of the rotor system tilted back but passing through a point a few feet above the center line of the fuselage and you will immediately see that the effect of a change in attitude of the rotor disc or cone results in a very distinct movement of the point of intersection of this lift vector and the center-line of the fuselage. And this vectorial movement is the reverse of that common in airplane design, for, with increase in forward speed, the machine becomes tail-heavy; consequently, the tail requirements are almost, if not quite, the reverse of those in the conventional airplane.

Also involved in the problem of dynamic balance is the very unfortunate and compromising situation which the designer meets when he discovers that the center of gravity of his design will be extremely high in the structure as compared with that of an airplane structure. This is due to the concentrated weight of the rotor system being located 3, 4 or more feet above the center-line of the fuselage.

This fact makes necessary the tilting of the engine forward at an angle that appears to be rather uncanny, so that the thrust line shall pass through or nearly through the center of gravity of the craft. The losses in efficiency as a result of this peculiar position of the engine have to be tolerated and are in any case small. Without this engine arrangement, the Autogiro would have a distinct "power-on, power-off" characteristic which would render flight over the very wide speed range of which the machines are capable quite impossible because of the impracticability of securing longitudinal stability over so wide a range of conditions.

Problem of Control in Flight and Descent

Closely associated with balance in the design is the question of control. Control in an airplane is based entirely upon relative velocity; but an Autogiro is capable of flight with relative velocity in such a direction that, under certain conditions, it would appear that control should be impossible; namely, in vertical descent. Fortunately, this is not quite the case, but the influence of this peculiar characteristic plays a very important part in the designer's choice of control surfaces and systems.

The problem is to design control surfaces which will provide light and satisfactory control at one extremity of the flight range, namely, at top speed approximating perhaps 115 or 120 m.p.h., and which at the same time will give adequate control for the same aircraft at the other extreme of its flight range, namely, in almost pure vertical descent. This is not a simple problem to solve. As in so many cases of aircraft design, a compromise is necessary, and, while the compromise is not always entirely satisfactory, we are still finding more ways and means for improving it.

In the design of the new Kellett Autogiro we decided upon the size of total tail area necessary to give dynamic stability in full flight and estimated the amount of that area which should be movable as elevators for control under full-flight conditions. We then went to the other end of the flight range, namely, zero forward speed, and determined as closely as we could how much movable area in that tail surface we could spare to give control under the conditions of pure vertical descent.

One may imagine that, theoretically, pure vertical descent involves the tail surfaces operating at 90-deg. incidence. This is not actually the case, because of the influence of the downwash of the rotor and the propeller slipstream. If it were not for that condition, I think that vertical-descent control would be an impossible problem with the present control systems.

Actually, we found in this particular design that the tail area could be divided so as to give enough control under all conditions. The result is a stabilizer having a very small stationary portion, all the rest of the tail area being turned into elevators. This arrangement gives a machine that is over-controllable at high speeds and is reasonably satisfactorily controllable in vertical descent.

With suitable proportioning of the leverages involved in operating the elevator control, so that for small movements of the stick there are relatively small movements of the elevators and for large movements of the stick the gear ratio appreciably changes and one secures very large movements of the elevators, an elevator-control system can be incorporated which will be effective over the entire range.

Balancing Work Done by the Elevators

This introduces an entirely new thought so far as balance is concerned. An adjustable stabilizer in an airplane that has practically no stabilizer would hardly be practical. It became necessary to develop what we call a Bungee system, that is, a mechanism capable of applying a spring bias upon the elevator control, so that over the entire range of flight the pilot can, at will, set the angular location at which the elevators will naturally trim without any force on the stick. This seems to be the most satisfactory way of providing the necessary balance condition over the entire range of flight velocity of which the Autogiro is capable. It attacks the problem right where the problem lies, by using the surfaces of greatest area to do the balancing work that is necessary; namely, the elevators.

Aileron control is not nearly as complicated as might be expected from the foregoing statements, for, located as they are, directly under the rotor system, the

ailerons are constantly operating in the downwash of the rotor and do not stall when the fixed wing of the machine is itself approaching geometrical angles usually associated with the stall.

Actually it has been found impossible to stall the fixed wing of an Autogiro even in vertical descent, owing to the influence of downwash from the rotor. In some designs the fixed wing appears to come extremely close to the stall, but this characteristic has no effect whatever upon the behavior of the machine. Fortunately, rotor downwash results in surprisingly good lateral control in near-vertical descent, while in pure vertical descent the slipstream has an important influence provided the ailerons extend almost to the wing roots.

Control of Rotor Speed

Passing on to another problem of control that is peculiar to an Autogiro, I want to call attention to the distinctly novel matter of exercising control over a rotor system. Aeronautic engineers understand that the rotor blades flap on horizontal hinges and are also free within limits to move in the plane of rotation

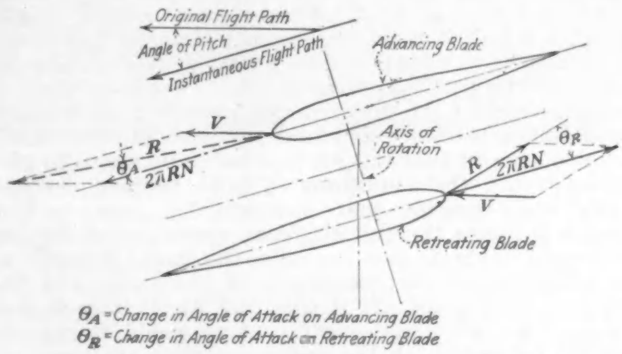


FIG. 1—ANALYSIS OF FORCES ACTING ON ROTOR BLADES IN A DIVE

When the Autogiro Is Tilted Downward, the Advancing Blade Momentarily Reduces and the Retreating Blade Increases Its Angle of Attack, Causing the Former To Fall and the Latter To Rise. This Influence Persists for a Fraction of a Second as Each Blade Comes into Lateral Position until the Locus of all the Blades again Becomes Perpendicular to the New Attitude of the Pylon and the Ship

about vertical hinges. A system of four blades, so flexibly mounted, introduces a distinct problem in control; yet, if those blades were rigidly mounted, not only would we lose the basic fundamental of the machine, namely, the equalization of the lift reaction on all sides of the rotor cycle, but we would introduce very severe inertia forces on the entire ship, which would make such a machine quite impossible of control in full flight. Hence we have to accept the articulations as essential and must provide the necessary control means so that the rotor system will always follow the ship in maneuvers.

Suppose, for example, that the revolutions per minute of the rotor were to vary directly as the horizontal speed of the ship through the air. In the first place, the rotor would have no revolutions in vertical descent, which would be a rather unfortunate situation; and, secondly, it would have perhaps too high revolutions in high-speed conditions. Apart from the basically inherent characteristic of the rotor to maintain fairly constant speed of rotation for a given design, the addition of a fixed wing in the system provides a means whereby the designer can fix the revolutions per minute of the rotor within certain very narrow limits and can design accordingly. The fixed wing also provides a means whereby the designer can increase the aerodynamic efficiency of the combination in terms of lift/drag ratio.

Relation of Fixed Wings to Rotor

Although fixed wings on the machine are not necessary, and Autogiros have flown without them, they greatly influence the efficiency. Suppose that a fixed wing is installed at an attitude such that it takes more and more lift as the speed of the ship increases. This it will do, since the lift varies as the square of the speed, given constant incidence. Then we immediately start robbing the rotor of lift, or rather the necessity to lift. Yet the fundamental theory of the rotor proves that lift is a primary requisite of autogyration. Such a combination as this will be characterized by a distinct tendency for the rotor to slow down as the forward speed increases, and this tendency may easily become so great as to be dangerous owing to the accompanying increase in coning angle.

If, on the other hand, the fixed-wing incidence is set so that, as the speed of the ship increases, the angle of balance is such that the fixed wing exercises a negative lift, the lift which the rotor must exercise is thereby increased and thus the revolutions per minute of the rotor are increased. Such a condition is not entirely satisfactory either, but, by presenting these two extremes, I believe it should be quite clear that a careful choice of fixed-wing area and incidence is possible and, when made, can result in a combination of rotor and fixed wing which gives constant or almost constant revolutions per minute for all conditions of flight. This is the basis of the fixed-wing design that we use today.

Actually, within the limits of Mr. Cierva's theory of a ratio of blade-tip velocity to horizontal translational velocity ranging from 6:1 to 1.5:1, a fixed-wing angle of attack approximately equal to the set pitch-angle of the blades results in a system that is entirely stable, so far as revolutions of the rotor are concerned. This assumes a fixed wing having a section identical with or closely similar to that of the rotor blade and a symmetrical section. It has been found advisable to locate this wing in such a position that its center of pressure is directly under the actual axis of rotation, that is, the line drawn through the rotor pylon axis, although specific design problems sometimes call for a location somewhat further aft. I emphasize the actual axis of rotation as differentiated from what I call the true axis of rotation, which is the virtual axis about which the blades rotate when coned up and when flapping. This axis is always tilted backward and is almost invariably to one side.

Response of Rotor to Machine's Maneuvers

Further in regard to the control of the rotor system is the question of compelling the rotor disc to follow the maneuvers of the ship. A glance at Fig. 1 will indicate that this particular problem is by no means complicated, being almost automatically solved. It must be realized that, while the blades are mounted universally, they are distinctly rigid in torque except insofar as their inherent structural flexibility is concerned. Therefore a longitudinal inclination of the rotor mast, as in a dive in flight, will result in an effective change in angle of attack of the two blades momentarily disposed along the lateral axis of the ship. If the tilt of the ship is as shown, the forward-moving blade will momentarily reduce its angle of attack, while the blade over the left wing-tip will increase in angle of attack. Thus the forward-moving blade will fall and the rearward-moving blade will rise. This influence will persist as each blade comes around into lateral position until, within a fraction of a second, the locus of all blades is again perpendicular to the new attitude of the pylon and ship. It will at once be seen that the phenomenon

immediately assures quick response of the rotor system as a whole to any and all maneuvers of the craft.

Yet another controlling element in the functioning of the rotor system and its behavior in relation to the rest of the machine occurs as a result of the tremendous inertia forces that are created in the rotating blades coupled with the moments due to the offsets of the horizontal articulation hinges. Reference to Fig. 2 will indicate clearly the generation of a restoring couple, the magnitude of which will be the difference between the centrifugal forces acting upon the opposite blades at the moment arms represented by d_1 and d_2. This couple may be of the order of 3000 or 4000 in.-lb. and is responsible to a considerable extent for the marked inherent stability of the Autogiro. The horizontal hinge in machines of present size is located approximately 3 in. from the axis of rotation.

The flexibility of the rotor system in a plane perpendicular to the plane of rotation completely frees the machine of gyroscopic precession, without which freedom flight with rotative wings is, in my opinion, quite impossible.

Control of Rotor-Blade Oscillations

Another form of control that the designer must consider in laying out a rotor system is that which arises from the fact that the flapping of a rotor blade results in oscillations in the plane of rotation, which must either be taken as bending of each blade in the plane of rotation or be set free with the aid of a vertical hinge. Rotors have been constructed without a vertical hinge and flight attempts have been made but the structural problems involved have not been solved. Inclusion of a vertical hinge in the articulation system of each blade presents the best and an immediately available means for freeing the system of the severe bending moments in the plane of rotation which result from the flapping of the blades.

Mr. Cierva calls this tendency to oscillate in the plane of rotation a kinematic oscillation, and he differentiates it from another tendency to oscillate in the plane of rotation which is caused by the rapidly fluctuating drag forces acting on each blade as it travels around the cycle during forward flight. On the up-wind side of the cycle the blade experiences a relative velocity of its own speed plus the speed of the ship, and on the down-wing side the drag is equivalent to a relative velocity equal to the difference between those two speeds.

This latter influence tending to move the blade about its vertical hinge is limited with the aid of flexible interbracing cables coupled with a damping device on each blade which tends to absorb the shock that would otherwise be transmitted to the blade as a severe torsional and bending moment were the bracing cables permitted to tighten up sharply. With the aid of such a flexible interbracing it has been found possible to eliminate all roughness in the rotor system due to the periodic oscillations in the plane of rotation resulting from fluctuations in the drag forces and during starting, but this bracing system does not in any way affect the kinematic oscillations. However, these are stable and are controlled by the restoring couple created by the offsetting of the vertical hinge from the center line of rotation.

The exact location that this vertical hinge must have in order to exercise the control that I have been discussing has for some time been a very difficult problem to solve. On his latest visit to America, Mr. Cierva carried out a number of extremely interesting experiments in this direction and evolved a theory which, put into practice, seems to be very sound. It ties up the natural pendula frequency of each blade with the revolutions per minute of the rotor in such a way that the control exercised by the fixed part of the rotor hub, that is, the part "in-board" of the vertical hinge, exactly compensates any tendency for the blade itself to become unstable in the plane of rotation.

We regard a rotor blade as a perfectly simple pendulum actuating as any other pendulum would, but in a horizontal plane, under the influence of a constant force—in this case, centrifugal force—and having superimposed upon its oscillations a constant rotation. It has been found that, with a satisfactory form of interbracing, an odd-numbered relationship between the virtual pendula frequency of the blade and the speed of rotation, such as 3:1, 5:1, 7:1 and so on, will give a system that will be stable and smooth in flight. To prove that an odd harmonic is sound for a rotor with interbracing, one has been constructed with this relationship and has performed satisfactorily.

Difficulties of Under-Carriage Design

Having covered rather briefly the two outstanding problems of control that the designer of an Autogiro faces, namely, control of the machine itself and control of the rotor, I should like to touch upon one other outstandingly important problem in design that calls for as much ingenuity as any other problem. I refer to the design of the under-carriage. An under-carriage is only something on which to land; we should like to dispense with it if we could do so, but in an Autogiro it becomes even a more important part of the structure, because landings have to be made under such abnormal conditions that an under-carriage is, for the most part, a bouncing ball.

An under-carriage which will have sufficient shock-absorbing quality to soften the impact of a load ranging from a ton up or down, depending upon the size of the ship, meeting the ground at a velocity equal to or slightly less than the speed of a parachute, is vastly different from an under-carriage designed to absorb

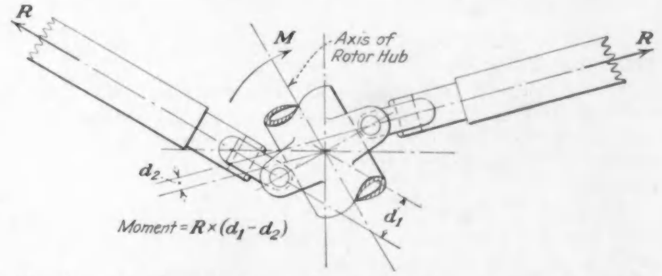


FIG. 2—RESTORING COUPLE GENERATED BY OFFSETS OF ARTICULATION HINGE AND INERTIA OF ROTATING BLADES

The Magnitude of the Couple Is the Difference between the Centrifugal Forces Acting on the Opposite Blade at the Moment-Arms d_1 and d_2. It May Be of the Order of 3000 or 4000 In-Lb.

the impact of an equivalent load in a smooth and gradual descent along an almost horizontal path. No appreciable spread of the wheels during the absorption of impact is tolerable; otherwise, the tires are immediately wiped off. Weight, too, presents a very major problem.

Reduction of air resistance is important, and I believe it is advisable to design the under-carriage structure as an integral part of the fuselage to stiffen the latter against flexion that is likely to arise from the inertia effects created by blade movements both on the ground and in the air and resulting from the concentrated weight of the rotor system supported high above the fuselage structure. Fig. 3 and the full side view of the Autogiro at the head of this paper show how this stiffness has been achieved with the aid of a quadruple structure which serves the dual purpose of bracing the open-cockpit bay of the fuselage and lowering the point of suspension of the axles sufficiently that the

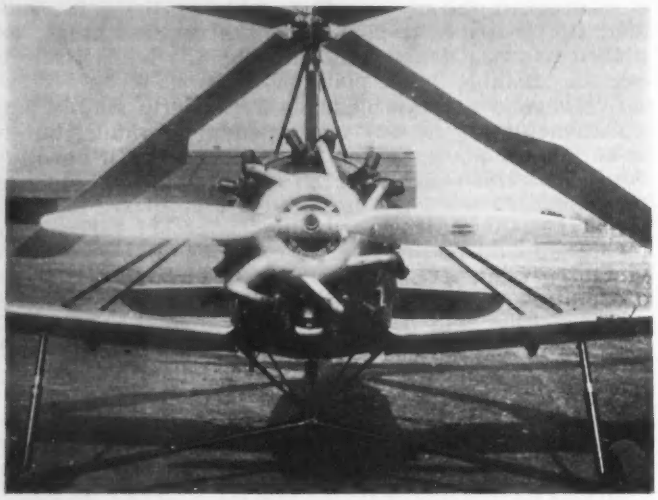


FIG. 3—FRONT VIEW OF KELLETT AUTOGIRO, SHOWING UNDER-CARRIAGE BRACING

The Landing-Gear Must Have Unusual Shock-Absorbing Capacity and the Wheels Must Not Spread Appreciably. The Bracing Stiffens the Fuselage against Inertia Loads Created During Taxiing and in Flight Due to the Weight and Location of the Rotor System and Lowers the Point of Suspension of the Axles Enough To Produce Spreading of the Wheels to the Minimum

spread of the wheels during shock absorption is extremely small.

Fortunately, the under-carriage does not have to perform the vary hard work that one would think, and it has been possible to design it to considerably lower load factors than is necessary in conventional airplanes.

Compromise of Rate and Angle of Climb

Before closing, I should like to point out some of the influences that enter into the performance calculations of an Autogiro system. Minimum speed is an outstanding characteristic and cannot be acquired without low disc-loading, which means fairly large rotor diameter.

The rate of climb increases with minimum speed and with decrease in rotor diameter, but we never have sought a high rate of climb in preference to angle of climb, provided the rate was within fairly close approximations of similar airplane performance.

Angle of climb fortunately also increases with rotor diameter and thus permits one to design an Autogiro which combines very slow horizontal speed with very high angle of climb.

Autogiros are extremely sensitive to weight, and therein lies the chief bone of contention between the designer and the sales manager, who wants to put gadgets on the ship that will assist him to sell the machine. This is in direct opposition to the designer's desire to eliminate all devices that are not necessary to a flying-ship. Conversely, an Autogiro is most favorably affected by any decreases in weight.

In conclusion, and in support of aeronautic-engineering progress, I plead for the adoption of a sufficiently open-minded attitude toward aircraft design as a whole to be willing to see apparently astonishing developments come and be proved practical, without feeling that, because they are novel, they necessarily cannot be right.

THE DISCUSSION

JOHN D. AKERMAN[3]:—Has an attempt been made to take the Autogiro off from water?

W. LAURENCE LEPAGE:—About a year ago Mr. Cierva constructed a seaplane Autogiro that performed very satisfactorily, largely, I am told, because the rotor acquired the necessary lift for take-off in a very short distance.

ASHLEY C. HEWITT[4]:—Is it not true that the Autogiro has no appreciable gliding angle when the engine is shut off, and must descend vertically?

MR. LEPAGE:—No, the machine performs exactly like an airplane. At present its lift/drag ratio is not quite as high as that of an equivalent airplane, hence the flattest gliding angle is not quite as flat, but the pilot has a choice of gliding angle all the way from a near-vertical descent to its minimum gliding angle, with the engine shut off.

FRANKLIN T. KURT[5]:—How does the rotor behave under inverted loading conditions?

MR. LEPAGE:—We design for inverted-load conditions, having in mind the condition introduced at the end of a steep climb if the pilot were suddenly to flatten out the ship, when the rotor would momentarily lose lift and therefore revolutions. However, each rotor blade has considerable weight—61 lb. in the machine shown in Fig. 3—and therefore has considerable inertia. Experimental tests indicate a momentary reduction in rotor revolutions of the order of 10 per cent during such a maneuver. Actual inverted flight never has and probably never will be attempted.

Effect of Increased Disc-Loading

RICHARD M. MOCK[6]:—What would be the action of the Autogiro with increased loading, especially regarding settling?

MR. LEPAGE:—The settling speed is almost directly proportional to the disc loading, which is very easy to keep low without appreciably increasing the structural weight of the ship, as blades of slightly greater length can be used with very considerable increases in the disc area.

Present Autogiros are flying with disc loadings of approximately 1.60 to 1.65 lb. per sq. ft., which is an extremely low loading. An increase in that loading will not cause any very material reduction in the aerodynamic efficiency. Fortunately, we are concerned, not with actual surface loading, but with the virtual surface or disc loading.

BROOKS WALKER[7]:—What is the attitude of the machine relative to the ground under the various gliding angles as compared with the attitude of a conventional airplane?

MR. LEPAGE:—It is equivalent or very similar. The ship takes a slightly nosed-down attitude in both gliding flight and vertical descent. A usual way to descend is to fly over a landing-field at 200 to 300 ft. altitude, and, when above the approximate spot at which it is desired to land, to pull the control stick back, idle the engine and descend nearly vertically, invariably touching the tail-skid first. The rotor adopts its own efficient attitude due to the articulations, regardless of the attitude of the ship.

[3] Professor and head of department of aeronautic engineering, University of Minnesota, Minneapolis.

[4] M.S.A.E.—President, Engineering Development Associates, Plainfield, N. J.

[5] Jun. S.A.E.—Engineer, Viking Flying Boat Co., New Haven, Conn.

[6] Jun. S.A.E.—Aeronautical engineer, with A. H. G. Fokker, New York City.

[7] Detroit.

Why the Rotor Has Four Blades

T. P. WRIGHT[8]:—What criteria determine the present use of four rotor blades rather than some other number? It might be thought that a greater number would make possible a decrease of the disc area.

MR. LEPAGE:—The choice of four blades is the result of Mr. Cierva's extensive experiments ranging all the way from two to five and, I believe, six blades. The difficulty involved in using more than four blades is the interference between them, which increases rapidly and causes marked inefficiency. The use of two blades produces roughness due to the necessary vertical articulations. Mr. Cierva believes that at present a four-blade rotor is the best compromise, and I agree with him, although further experimentation may prove a three-blade rotor to be very satisfactory from all considerations.

If you plot three symmetrically located blades on a piece of paper and drop any datum line across those blades at any angle passing through the center, you will always find a relative location of masses which, revolved about that axis on the two sides, will be equal. That cannot be done with the four-blade rotor, and I believe that has an appreciable bearing upon the smoothness of a three-blade system.

W. W. GERHARDT[9]:—Do you place any faith in free-flight performance of a model of reasonably large size? I have witnessed the evolution of several models built by some of Detroit's model makers, and a number of times have witnessed these models on their backs in pulling out of unusual evolutions in a very interesting manner. The rotor was not made strictly according to the way you build it; instead of articulated joints, the blades were of flexible bamboo and steel. I am curious to know if Mr. Cierva has ever investigated the flight characteristics with models.

Mr. LEPAGE:—Mr. Cierva's first insight into the possibilities of an articulated system was with such a model. He built a model of his first Autogiro which was supposed to have rigid blades but which, due to the structural characteristic of the model, developed so much flexibility in flight that flight was made possible, which would otherwise not have been the case.

Few if any of the models that have come under my direct observation have derived any real lift from the rotor in forward flight. The rotor probably was more of a hindrance than an adjunct to forward flight, the fixed wing doing all the real work.

I believe that, with an appropriate apparatus, experiments with models could be made to develop very interesting results. The first and foremost problem is the solution of the scale effect in rotating systems, because, without its solution, we cannot take any further steps in the direction of model research. Solution of that problem—and I believe it can be solved—will immediately, in my opinion, open a tremendous realm of possibility in model research, both in free flight and particularly in wind-tunnels, which would throw light on all of the questions which are at present baffling us.

MR. GERHARDT:—One of the models I referred to had no wing at all, only two very small surfaces with a slight pitch to overcome the torque of the propeller. That might suggest that perhaps the rotor had complete stability against inverted flight even without a wing.

MR. LEPAGE:—An Autogiro is stable in vertical descent by reason of sheer pendula stability, but in inverted flight such stability does not exist. No doubt the model you have in mind had weights much more closely united than they would be in an equivalent airplane.

MR. HEWITT:—Have you any information as to how large an Autogiro can be made and how little horsepower can be used to fly it?

MR. LEPAGE:—There is no apparent limit to the size either way. So far as load-carrying capacity is concerned, the swept-disc area of the rotor has a great deal to do with limiting the capacity. The swept-disc area of a rotor system can be doubled without increasing in the same proportion the actual rotor diameter and therefore the structural problems which are almost proportional to linear size. Building very light rotors, and therefore very small and light Autogiros, seems quite feasible. The basic influence that enters into all such calculations is the fact that the rotor system cannot be lightened below a certain amount for a given weight of ship without having a very high coning angle, and approximately 9 to 10 deg. is all that the theory can tolerate.

Not Limited to Low Speed

RALPH H. UPSON[10]:—One common misapprehension, particularly among engineers, is that the Autogiro is limited to relatively low speeds. That seems to me to be radically wrong, because, from a practical viewpoint, the biggest problem in making a fast airplane is to make it able to go slow. From a purely practical viewpoint, it seems to me that the main field for the Autogiro is in relatively high-speed work and that, for economic and other reasons, it cannot compete easily with small, light, cheap and necessarily low-speed airplanes.

MR. LEPAGE:—I believe that you are correct. The reason that we Autogiro men, as a whole, have emphasized low speed is because the machine has been introduced with a view to safety in operation, and the minimum speed of an airplane apparently is one of the major characteristics that limit its safety. The fact that the Autogiro can be momentarily stopped in the air and then slowly descend is its outstanding characteristic. However, I believe it to be entirely possible, for example, to put a smaller, properly proportioned rotor on a small Autogiro and produce a ship of extremely high speed, which, nevertheless, will be capable of being landed at 30 m.p.h. or so, the speed range remaining approximately as it is now. Such a ship would still be capable of being landed by a good pilot without any appreciable forward speed at the moment of impact, because of the ability of the pilot to make what we commonly call the "chicken landing" by presenting the entire disc to break the forward velocity. The rotor has considerable inertia and will not speed up in proportion to the sudden increase in lift that it is capable of exerting at the increased disc angle and so will let the ship down before the rotational speed can be increased sufficiently to cause a zoom.

P. ALTMAN[11]:—Since the resultant force varies in magnitude and direction with the speed of the rotor, what condition of flight actually determines the design position of the center of gravity with respect to the center of rotation? Also, since the unbalanced couple would change with the speed, what should be the optimum position of the center of gravity?

MR. LEPAGE:—We locate the center of gravity approximately 1 to 2 in. ahead of the true center line of rotation. That means about 2 or 3 deg., and that condition for existing designs of the type we have been discussing provides a ship that is longitudinally stable throughout the entire speed range, provided the location of the fixed wing is as I outlined in the paper and the incidence of the rotor is approximately 2 to 2.5 deg.

---

[8] M.S.A.E.—Vice-president, chief engineer, Curtiss Aeroplane & Motor Co., Garden City, N. Y.

[9] Professor of aeronautic engineering, College of the City of Detroit.

[10] M.S.A.E.—Aeronautic engineer, Red Bank, N. J.

[11] M.S.A.E.—Professor of aeronautic engineering, director of aeronautics department, University of Detroit.

Why Fixed Wing Does Not Stall

MR. UPSON:—You made the statement that, even in vertical descent, the fixed wing could not be stalled. To achieve that condition, a very plausible proposition is that the downwash from the rotor as a whole must be approximately equal to the rate of descent of the aircraft as a whole; so naturally, if the fixed wing is in a central position, where it is commonly put, and is in a condition of no resultant air-flow, the wing will not stall but neither will any other effect be obtained from it.

MR. LEPAGE:—Perhaps I did not make myself quite clear. I speak of the fixed wing not operating in a condition where it is not stalled in relation to the effect of the aileron. Were the aileron to be influenced only by a normal velocity, the pilot would have no aileron control. With the aileron influenced by a velocity having a distinct component, the pilot does have aileron control even in vertical descent.

MR. UPSON:—Where do you get that component? Is it just a radial outward component?

MR. LEPAGE:—It is the resultant between the relative vertical velocity and the downwash of the rotor system. At the central line of rotation the inflow is equivalent to the downward relative velocity. That inflow decreases with the distance outward from the center.

MR. UPSON:—But at a point directly below the center of the rotor, in a true vertical descent, the very symmetry of the motion would give no resultant flow of air, except a very small axial flow.

MR. LEPAGE:—We have attached streamers at the location of the fixed wing on large-scale models of rotors and observed the direction of the downflow and proved that a distinct horizontal component exists over the fixed wing under all conditions. The Autogiro Co. of America also has experimented upon full-scale fixed wings with streamers under all conditions of flight.

WALTER C. CLAYTON[12]:—Strictly speaking, what we refer to as vertical descent is not quite vertical. The machine has a slight forward motion of 10 to 15 m.p.h. because the center of gravity is located slightly forward of the axis of rotation, causing the machine to dip its nose slightly and glide, as would a stable airplane.

MR. LEPAGE:—I take it that Mr. Clayton does not intend to create the impression that strictly vertical descent is not possible.

MR. CLAYTON:—No, I do not mean to infer that, but simply that, in strictly vertical descent, as Mr. Upson pointed out, it would be rather difficult to get adequate control. If an Autogiro were making a pure vertical descent (zero forward air-speed) and the engine should stop, the machine would continue its descent in stable equilibrium but within control, very much as would a parachute. On the other hand, if an Autogiro were making a normal vertical descent with some forward speed and the engine should stop, the pilot would have complete longitudinal, lateral and directional control enabling him to maneuver the machine throughout the descent. There is another advantage in maintaining some forward headway during vertical descent; namely, that of overcoming the velocity of the wind. An Autogiro, like an airplane, is landed pointing into the wind. If it were to make a pure vertical descent pointing into, say, a 10-m.p.h. wind, it would land going backward 10 m.p.h., as is frequently done while landing in a high wind. On the other hand, an Autogiro having a 15-m.p.h. forward speed and landing in a 10-m.p.h. wind would land with a 5-m.p.h. forward ground-speed.

Rotor Stresses and Landing Side-Thrust

EDWARD P. WARNER[13]:—Has any experiment been made to determine the loads on the rotor system and the effect on the rate of revolution of the rotor in the presence of vertical air currents of ordinary or extraordinary magnitude; first, as to the stresses in the rotor blades themselves, and, second, as to the acceleration of the whole structure? Further, has any comparison been made of the acceleration shown by the Autogiro and a conventional airplane while flying at approximately the same speed through bumpy air?

Back in 1910 the Bleriot XI had a landing-gear which was able to taxi sideways. The tendency to do that made taxying control somewhat difficult, but such a landing-gear seems to have possibilities for the Autogiro, assuming that the mechanism could be locked to eliminate the side-swaying during the take-off, but permitting landing sideways, backward or forward with equal freedom.

MR. LEPAGE:—So far as I know, no actual measurements have been made of forces or behavior of a rotor system in rough-air flying at a maximum velocity such that any further increase in velocity due to gusts would produce an overload. Observations that have been made and a careful study of autogyration and rotor theory indicate that the flexibility of the structure plus its inherent inertia relieves it of the overloads that otherwise would appear to be imposed under such conditions. The rotor derives its lift entirely from its autogyration, and momentary increases in relative velocity without equivalent increases in total velocity over the entire disc are merely absorbed within one blade and taken up in the articulation hinge. We provide for overload conditions in the structural design of the rotor blades and spars, calculating such conditions for 25 per cent in excess of maximum velocity.

I think that your suggestion regarding the landing-gear is very sound. It introduces certain structural complications, such as the difficulty of providing a relatively movable point of contact between the airplane and the ground; but some type of gear that could be designed so as to limit that peculiar condition and also which could be tracked for taxying purposes and for landing with speed might solve any difficulty that we should have from side thrust on the tires. However, we have had no serious trouble with this, due to the type of under-carriage system we are putting out at present. If an attempt were made to land an Autogiro in a side wind, it would suffer from the same compromising situation that any other airplane would.

[12] Chief engineer, Pitcairn Aircraft, Inc., Willow Grove, Pa.
[13] M.S.A.E.—Editor, *Aviation*, New York City.

Bearing-Load Analysis and Permissible Loads as Affected by Lubrication in Aircraft Engines—II[1]

19th National Aeronautic Meeting Paper

By Ford L. Prescott and Roy B. Poole

THIS analysis will serve to illustrate the standard or typical graphical method, as applied to the solution of bearing loads for a nine-cylinder radial-engine. Engine characteristics and dimensions are given in Table 13, the data being obtained from detail drawings and laboratory tests.

Gas-Pressure Forces.—Fig. 19 represents an indicator diagram drawn for the master-rod cylinder, in which gas pressure in pounds per square inch is plotted versus per cent of piston travel.

The brake mean effective pressure

$$\text{b.m.e.p.} = (792{,}000 \times 525)/1750 \times 1900$$
$$= 125.0 \text{ lb. per sq. in.}$$

The mechanical efficiency is assumed to be 90 per cent, hence,

$$\text{i.m.e.p.} = 125.0/0.90 = 139.0 \text{ lb. per sq. in.}$$

Theoretical pressure at the end of the expansion stroke is computed as for the V-engine; however, due to a slight boost given by the rotary induction-system, also ram due to induction pipes, absolute pressure in the cylinder at the beginning of compression can be taken as 15.0 lb. per sq. in., hence,

$$P_d = ([(1.30 - 1)(5.0 - 1)]/[(5.0)^{1.3} - 5.0])(139.0/0.90) + 15$$
$$= 74.6 \text{ lb. per sq. in., absolute}$$

The clearance volume is

$$V_d = 100\,[1/(5.0 - 1)]$$
$$= 25 \text{ per cent}$$

The gas pressure in pounds per square inch, absolute,

[1] The first part of this paper which is herewith concluded, was published in the S.A.E. JOURNAL for October, 1931, on p. 296. Mr. Prescott who is a Service Member of the Society, is senior mechanical research engineer, and Mr. Poole is assistant mechanical engineer of the powerplant branch, both with the materiel division of the Air Corps, Wright Field, Dayton, Ohio.

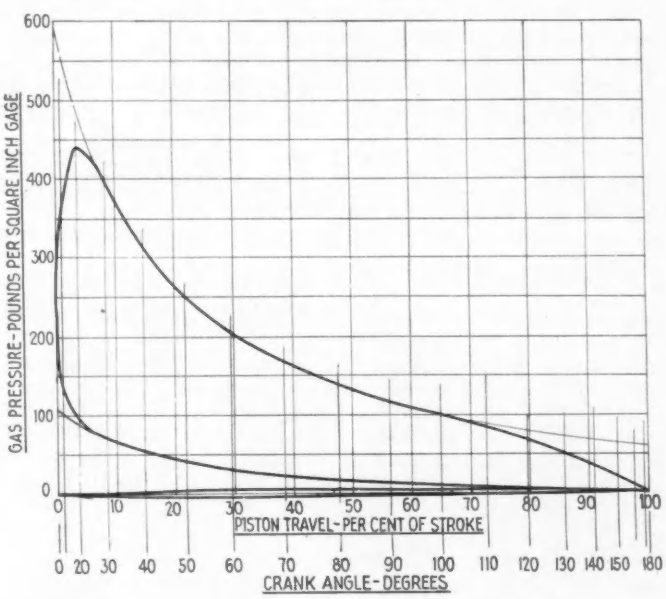


FIG. 19—INDICATOR DIAGRAM OF THE WRIGHT R-1750 CYCLONE ENGINE

The Data from Which This Diagram Was Plotted Are

Indicated Mean Effective Pressure, lb. per sq. in.	139.0
Compression-Ratio	5.00 : 1
Exponent of Expansion and Compression Curves	1.30
Diagram Factor	0.90
Maximum Pressure, lb. per sq. in.	440

TABLE 13—ENGINE CHARACTERISTICS AND DIMENSIONS OF WRIGHT R-1750 CYCLONE ENGINE

Number of Cylinders	9
Arrangement of Cylinders	Radial
Numbering of Cylinders	1 to 9 consecutively, clockwise facing rear of engine, No. 1 vertical and on top
Firing Order	1, 3, 5, 7, 9, 2, 4, 6, 8
Crankshaft Rotation	Clockwise facing rear of engine
Bore, in.	6.000
Stroke of Master-Rod, Cylinder (2R), in.	6.875
Piston Area, (A_p) sq. in.	28.27
Total Piston Displacement, cu. in.	1,750
Brake Horsepower	525
Speed, r.p.m.	1,900
Compression Ratio	5.0 :1
Mechanical Efficiency, Assumed, per cent	90
Brake Mean Effective Pressure, lb. per sq. in.	125.0
Indicated Mean Effective Pressure, lb. per sq. in.	139.0
Master Connecting-Rod Length, Center to Center, (L), in.	13.750
Master Connecting-Rod to Crank Ratio, (L/R)	4.000
Articulated or Link-Rod Length, in.	11.046
Master Rod Is Assembled in Cylinder No. 7	
Valve Timing	
Inlet Valve Opens, deg. before Top Dead-Center	25
Inlet Valve Closes, deg. after Bottom Dead-Center	60
Exhaust Valve Opens, deg. before Bottom Dead-Center	80
Exhaust Valve Closes, deg. after Top Dead-Center	25
Valve Tappet Clearance, in.	0.050
Epark-Advance, deg. before Top Dead-Center	30
Supercharger	
Type	Geared centrifugal
Impeller Speed	8 times crankshaft
Reciprocating and Rotating Weights	
Reciprocating Weight per Cylinder of Master Rod, lb.	7.45
Piston, Complete with Rings and Pin, lb.	5.34
Upper End of Master Connecting-Rod, lb.	2.11
Reciprocating Weight per Cylinder of Link Rod, lb.	6.74
Upper End of Link Connecting-Rod, lb.	1.40
Rotating Weight at Crankpin, (W_c) lb.	25.22
Lower End of Master Connecting-Rod, lb.	15.62
Lower End of Link Connecting-Rod, lb.	1.20
Crankpin-Bearing Dimensions	
Diameter, in.	3.250
Length, Total, in.	3.906
Length, Effective, in.	3.562
Effective Projected Bearing Area, sq. in.	11.58
Front Main-Bearing	
Construction	Steel shell lined with high-lead bronze
Diameter, in.	4.375
Effective Length, in	1.6875
Effective Projected Bearing Area, sq. in.	7.38
Rear Main-Bearing	
Type	Commercial Hoffman R-190-LL or SKF Light Series Roller Bearing No. 8218-C
Inner Diameter, in.	3.5433
mm.	90
Outside Diameter, in.	6.2992
mm.	160
Width, in.	1.181
mm.	30
Front Thrust-Bearing	
Type	Commercial Standard S.A.E. Light-Series Ball Bearing No. 218
Inner Diameter, in.	3.5433
mm.	90
Outside Diameter, in.	6.2992
mm.	160
Width, in.	1.181
mm	30

TABLE 14—GAS PRESSURES IN THE WRIGHT R-1750 ENGINE

x Piston Travel, Per Cent	$x + 25.0$	$\frac{125.0}{x+25.0}$	$\left(\frac{125.0}{x+25.0}\right)^{1.3}$	Gas Pressure, Lb. per Sq. In. Absolute Compression	Absolute Expansion	Gage Compression	Gage Expansion
0	25.0	5.000	8.103	121.6	604.5	106.9	589.8
10	35.0	3.572	5.233	78.5	390.2	63.8	375.5
20	45.0	2.778	3.775	56.6	281.6	41.9	266.9
30	55.0	2.272	2.906	43.6	216.7	28.9	202.0
40	65.0	1.923	2.340	35.1	174.5	20.4	159.8
50	75.0	1.666	1.942	29.1	144.8	14.4	130.1
60	85.0	1.470	1.650	24.7	126.0	10.0	108.3
70	95.0	1.315	1.428	21.4	106.4	6.7	91.7
80	105.0	1.190	1.254	18.8	93.6	4.1	78.9
90	115.0	1.086	1.113	16.7	83.0	2.0	68.3
100	125.0	1.000	1.000	15.0	74.6	0.3	59.9

for a given per cent of piston travel, x, is, for the compression stroke,

$$P_{x1} = 15.0\,[125.0/(x + 25.0)]^{1.3}$$

and for the expansion stroke

$$P_{x2} = 74.6\,[125.0/(x + 25.0)]^{1.3}$$

From these equations, gas pressures are computed for every 10 per cent of piston travel and absolute pressures so obtained reduced to gage pressures. Table 14 gives gas pressures for the compression and expansion strokes. From this table, the indicator diagram, Fig. 19, is drawn, corners being rounded in a manner similar to test diagrams. Values of gas pressure for intake and exhaust strokes are also proportioned from test diagrams. A scale showing the per cent of piston travel for various crank-angles is then plotted on this diagram, so that gas pressures at any crank-angle can be determined directly.

Piston Motion and Connecting-Rod Angles.—In Table 15 are given the angle φ that the connecting-rod makes with the cylinder axis, per cent of piston travel, piston-velocity factor f_v, piston-acceleration factor f_a, inertia force acting along the cylinder axis F_i, inertia force acting along the connecting-rod axis and secant of connecting-rod angle for 10-deg. intervals of crank rotation. For any given crank-angle Θ, the corresponding rod-angle is found from the relation $\varphi = \sin^{-1}[(R/L) \sin\Theta]$, per cent of piston travel and factors f_v and f_a being obtained from Table 16.

An articulated-rod construction is employed in this engine, hence the link-rod rotating-ends do not travel in a true circular path at crank radius. However, this effect on the bearing load is small and in the present case is neglected. Taking the average reciprocating-weight per cylinder as 6.82 lb., the inertia force F_i along the cylinder axis is calculated as follows:

$$F_i = -\,28.4 \times 10^{-6} \times 6.82 \times 3.4375 \times (1900)^2 \times f_a$$

or

$$F_i = -\,2405\,f_a$$

To construct a polar diagram showing the resultant inertia-force due to all reciprocating weights of the engine—nine pistons and rod ends—inertia force acting along the connecting-rod axis F_{ir} is computed from the equation $F_{ir} = F_i \sec\varphi$.

Referring now to Table 17, gas pressures in pounds per square inch are obtained from the indicator diagram, Fig. 19, for 10-deg. intervals of crank rotation throughout the engine cycle. These pressures multiplied by the area of piston, 28.27 sq. in., give total gas-pressure force F_g acting on the piston. The resultant force acting on the piston in the direction of the cylinder axis, F_a, is obtained at various crank-angles by adding algebraically the inertia force and gas force for the crank angles considered or $F_a = F_i + F_g$. Resultant force along the connecting-rod axis due to both gas pressure and inertia is, therefore, $F_{ar} = F_a \sec\varphi$. Complete results of calculations are given in Table 17.

Forces of the link-rod cylinders are considered to be the same as those computed for the master-rod cylinder

TABLE 15—PISTON MOTION, CONNECTING-ROD ANGLES AND INERTIA FORCE ACTING ALONG CYLINDER AND CONNECTING-ROD AXES IN A WRIGHT R-1750 ENGINE

θ Crank Angle, Deg.		ϕ Connecting-Rod Angle, Deg.	Min.	Piston Travel, Per Cent	f_v Piston-Velocity Factor	f_a Piston-Accelera-tion Factor	Sec ϕ	Inertia Force, Lb. F_i Along Cylinder Axis	F_{ir} Along Connecting-Rod Axis
0	360	0	00	0.0	0.000	1.250	1.0000	−3,008	−3,008
10	350	2	29	0.9	0.216	1.220	1.0009	−2,935	−2,938
20	340	4	54	3.7	0.423	1.131	1.0037	−2,720	−2,730
30	330	7	11	8.3	0.609	0.991	1.0079	−2,382	−2,400
40	320	9	15	14.3	0.768	0.809	1.0132	−1,947	−1,970
50	310	11	3	21.6	0.891	0.600	1.0189	−1,443	−1,470
60	300	12	30	29.7	0.977	0.375	1.0243	− 902	− 925
70	290	13	35	38.5	1.022	0.151	1.0288	− 363	− 373
80	280	14	15	47.5	1.029	−0.061	1.0317	147	152
90	270	14	29	56.4	1.000	−0.250	1.0328	602	622
100	260	14	15	64.8	0.941	−0.409	1.0317	984	1,018
110	250	13	35	72.7	0.857	−0.534	1.0288	1,284	1,320
120	240	12	30	79.7	0.755	−0.625	1.0243	1,504	1,540
130	230	11	3	85.8	0.641	−0.686	1.0189	1,650	1,680
140	220	9	15	90.9	0.518	−0.723	1.0132	1,738	1,760
150	210	7	11	94.9	0.391	−0.741	1.0079	1,782	1,795
160	200	4	54	97.7	0.261	−0.749	1.0037	1,800	1,810
170	190	2	29	99.3	0.131	−0.750	1.0006	1,804	1,806
180	180	0	00	100.0	0.000	−0.750	1.0000	1,804	1,804

TABLE 16—DATA ON PISTON TRAVEL AND PISTON-ACCELERATION AND PISTON-VELOCITY FACTORS FOR VARIOUS CRANK-ANGLES IN A WRIGHT R-1750 ENGINE

θ Crank Angle, Deg.		Values of L/R 3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4
		Piston Travel, Per Cent							
0	360	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	350	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
20	340	4.0	3.9	3.8	3.8	3.7	3.7	3.7	3.6
30	330	8.8	8.7	8.6	8.5	8.4	8.3	8.2	8.1
40	320	15.2	15.0	14.8	14.6	14.4	14.3	14.2	14.1
50	310	22.8	22.5	22.3	22.1	21.8	21.6	21.4	21.2
60	300	31.4	31.0	30.6	30.3	30.0	29.7	29.5	29.3
70	290	40.5	40.0	39.6	39.2	38.8	38.5	38.2	37.9
80	280	49.6	49.1	48.7	48.2	47.8	47.5	47.2	46.9
90	270	58.6	58.0	57.5	57.1	56.7	56.4	56.1	55.8
100	260	67.0	66.5	66.0	65.6	65.2	64.8	64.5	64.2
110	250	74.7	74.2	73.8	73.4	73.0	72.7	72.4	72.1
120	240	81.4	81.0	80.6	80.3	80.0	79.7	79.5	79.3
130	230	87.1	86.8	86.5	86.3	86.0	85.8	85.6	85.5
140	220	91.8	91.6	91.4	91.2	91.0	90.9	90.8	90.7
150	210	95.4	95.3	95.2	95.1	95.0	94.9	94.8	94.7
160	200	98.0	97.9	97.8	97.8	97.7	97.7	97.7	97.7
170	190	99.5	99.5	99.4	99.4	99.3	99.3	99.3	99.3
180	180	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		f_a *Crank-Angle Factor for Piston Acceleration*							
0	360	1.333	1.313	1.294	1.278	1.263	1.250	1.238	1.227
10	350	1.298	1.279	1.261	1.246	1.232	1.220	1.209	1.198
20	340	1.195	1.179	1.165	1.153	1.142	1.131	1.122	1.114
30	330	1.033	1.022	1.013	1.005	0.998	0.991	0.985	0.980
40	320	0.824	0.820	0.817	0.814	0.812	0.809	0.807	0.806
50	310	0.585	0.589	0.592	0.595	0.597	0.600	0.602	0.604
60	300	0.333	0.344	0.353	0.361	0.368	0.375	0.381	0.386
70	290	0.087	0.103	0.117	0.129	0.140	0.151	0.160	0.168
80	280	—0.139	—0.120	—0.103	—0.087	—0.073	—0.061	—0.050	—0.040
90	270	—0.333	—0.313	—0.294	—0.278	—0.263	—0.250	—0.238	—0.227
100	260	—0.486	—0.467	—0.450	—0.435	—0.421	—0.409	—0.397	—0.387
110	250	—0.597	—0.581	—0.567	—0.555	—0.544	—0.534	—0.524	—0.516
120	240	—0.667	—0.656	—0.647	—0.639	—0.632	—0.625	—0.619	—0.614
130	230	—0.701	—0.697	—0.694	—0.691	—0.688	—0.686	—0.684	—0.682
140	220	—0.708	—0.712	—0.715	—0.718	—0.720	—0.723	—0.725	—0.727
150	210	—0.699	—0.710	—0.719	—0.727	—0.734	—0.741	—0.747	—0.753
160	200	—0.684	—0.700	—0.714	—0.727	—0.738	—0.749	—0.757	—0.765
170	190	—0.672	—0.691	—0.708	—0.724	—0.738	—0.750	—0.761	—0.771
180	180	—0.666	—0.688	—0.706	—0.722	—0.737	—0.750	—0.762	—0.773
		f_v *Crank-Angle Factor for Piston Velocity*							
0	360	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	350	0.231	0.227	0.224	0.221	0.218	0.216	0.214	0.212
20	340	0.450	0.443	0.437	0.432	0.427	0.423	0.419	0.415
30	330	0.646	0.637	0.629	0.622	0.615	0.609	0.604	0.599
40	320	0.811	0.799	0.790	0.782	0.775	0.768	0.762	0.756
50	310	0.936	0.924	0.915	0.906	0.898	0.891	0.885	0.880
60	300	1.017	1.007	0.998	0.990	0.983	0.977	0.971	0.966
70	290	1.053	1.045	1.038	1.032	1.027	1.022	1.018	1.015
80	280	1.045	1.041	1.037	1.034	1.031	1.029	1.027	1.025
90	270	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
100	260	0.925	0.929	0.932	0.935	0.938	0.941	0.943	0.945
110	250	0.827	0.835	0.841	0.847	0.852	0.857	0.861	0.865
120	240	0.715	0.725	0.734	0.742	0.749	0.755	0.761	0.766
130	230	0.596	0.608	0.617	0.626	0.634	0.641	0.647	0.652
140	220	0.475	0.486	0.495	0.503	0.511	0.518	0.524	0.530
150	210	0.354	0.363	0.371	0.378	0.385	0.391	0.396	0.401
160	200	0.234	0.241	0.247	0.252	0.257	0.261	0.265	0.269
170	190	0.117	0.120	0.123	0.126	0.129	0.131	0.133	0.135
180	180	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

at corresponding phases of their cycles. With this assumption, we only need to find the resultant force on the crankpin through an angle of $(720/9) = 80$ deg. for a nine-cylinder engine. The top cylinder is taken as No. 1 and cylinders are numbered in the direction of crank rotation, that is, right hand facing the rear of the engine. The firing order is 1-3-5-7-9-2-4-6-8. When Cylinder No. 1 is at 0 deg., beginning its firing stroke, the following cyclic relation exists in the various cylinders: No. 1 is at 0 deg., No. 2 is at 320 deg., No. 3 is at 640 deg., No. 4 is at 240 deg., No. 5 is at 560 deg., No. 6 is at 160 deg., No. 7 is at 480 deg., No. 8 is at 80 deg. and No. 9 is at 400 deg. Table 18 is now prepared, giving resultant forces along each connecting-rod axis at intervals of 10 deg. of crank angle, the crank angle in this case being taken with respect to the cylinder No. 1. The cycle of force variation repeats itself at 80-deg. intervals of the crank angle, hence only this duration need be considered.

The centrifugal force acting at the crankpin in the direction of the crank throw is

$$F_c = 28.4 \times 10^{-6} \times 25.22 \times 3.4375 \times (1900)^2$$
$$= 8890 \text{ lb.}$$

TABLE 17—RESULTANT FORCE ALONG CONNECTING-ROD AXIS OF A WRIGHT R-1750 ENGINE AT 1900 R.P.M.

θ Crank Angle, Deg.	p_g Gas Pressure, Lb. per Sq. In.	F_g Gas Force, Lb.	f_a Accleration Factor	F_i Inertia Force, Lb.	Resultant Force, Lb. F_a Along Cylinder Axis	F_{ar} Along Connecting-Rod Axis	Sec ϕ Secant of Connecting-Rod Angle
0	215.0	6,080	1.250	—3,008	3,072	3,072	1.000
10	340.0	9,610	1.220	—2,935	6,675	6,682	1.001
20	440.0	12,440	1.131	—2,720	9,720	9,759	1.004
30	400.0	11,300	0.991	—2,382	8,918	8,990	1.008
40	317.0	8,960	0.809	—1,947	7,013	7,100	1.013
50	254.0	7,180	0.600	—1,443	5,737	5,842	1.019
60	204.0	5,770	0.375	—902	4,868	4,988	1.024
70	165.0	4,665	0.151	—363	4,302	4,430	1.029
80	136.0	3,845	—0.061	147	3,992	4,122	1.032
90	115.0	3,250	—0.250	602	3,852	3,980	1.033
100	99.0	2,800	—0.409	984	3,784	3,908	1.032
110	83.0	2,347	—0.534	1,284	3,631	3,740	1.029
120	67.0	1,894	—0.625	1,504	3,398	3,480	1.024
130	50.0	1,413	—0.686	1,650	3,063	3,122	1.019
140	34.0	962	—0.723	1,738	2,700	2,735	1.013
150	18.0	509	—0.741	1,782	2,491	2,510	1.008
160	9.0	254	—0.749	1,800	2,054	2,062	1.004
170	3.0	85	—0.750	1,804	1,889	1,891	1.001
180	2.0	57	—0.750	1,804	1,861	1,861	1.000
190	2.0	57	—0.750	1,804	1,861	1,863	1.001
200	2.1	59	—0.749	1,800	1,859	1,867	1.004
210	2.2	62	—0.741	1,782	1,844	1,859	1.008
220	2.3	65	—0.723	1,738	1,803	1,825	1.013
230	2.5	71	—0.686	1,650	1,721	1,754	1.019
240	2.6	74	—0.625	1,504	1,578	1,615	1.024
250	2.8	79	—0.534	1,284	1,363	1,403	1.029
260	2.9	82	—0.409	984	1,066	1,100	1.032
270	2.9	82	—0.250	602	684	706	1.033
280	2.8	79	—0.061	147	226	233	1.032
290	2.4	68	0.151	—363	—295	—304	1.029
300	1.9	54	0.375	—902	—848	—868	1.024
310	1.2	34	0.600	—1,443	—1,409	—1,436	1.019
320	0.6	17	0.809	—1,947	—1,930	—1,954	1.013
330	—0.1	—3	0.991	—2,382	—2,385	—2,404	1.008
340	—0.6	—17	1.131	—2,720	—2,737	—2,748	1.004
350	—0.9	—25	1.220	—2,935	—2,960	—2,963	1.001
360	—1.0	—28	1.250	—3,008	—3,036	—3,036	1.000
370	—1.2	—31	1.220	—2,935	—2,966	—2,969	1.001
380	—1.9	—54	1.131	—2,720	—2,774	—2,785	1.004
390	—2.8	—79	0.991	—2,382	—2,461	—2,481	1.008
400	—4.0	—113	0.809	—1,947	—2,060	—2,087	1.013
410	—4.9	—138	0.600	—1,443	—1,581	—1,612	1.019
420	—5.4	—153	0.375	—902	—1,055	—1,080	1.024
430	—5.3	—150	0.151	—363	—513	—526	1.029
440	—4.8	—136	—0.061	147	11	11	1.032
450	—4.2	—119	—0.250	602	483	499	1.033
460	—3.6	—102	—0.409	984	882	910	1.032
470	—3.0	—85	—0.534	1,284	1,199	1,235	1.029
480	—2.4	—68	—0.625	1,504	1,436	1,470	1.024
490	—1.8	—51	—0.686	1,650	1,599	1,630	1.019
500	—1.2	—34	—0.723	1,738	1,704	1,726	1.013
510	—0.7	—20	—0.741	1,782	1,762	1,776	1.008
520	—0.2	—6	—0.749	1,800	1,794	1,802	1.004
530	0.1	3	—0.750	1,804	1,801	1,803	1,001
540	0.3	8	—0.750	1,804	1,812	1,812	1.000
550	0.4	11	—0.750	1,804	1,815	1,817	1.001
560	0.7	20	—0.749	1,800	1,820	1,826	1.004
570	1.2	34	—0.741	1,782	1,816	1,830	1.008
580	1.9	54	—0.723	1,738	1,792	1,815	1.013
590	2.8	79	—0.686	1,650	1,749	1,782	1.019
600	4.0	113	—0.625	1,504	1,617	1,656	1.024
610	6.0	170	—0.534	1,284	1,454	1,496	1.029
620	8.0	226	—0.409	984	1,210	1,250	1.032
630	12.0	339	—0.250	602	941	972	1.033
640	16.0	452	—0.061	147	599	618	1.032
650	21.0	594	0.151	—363	231	238	1.029
660	29.0	820	0.375	—902	—82	—84	1.024
670	40.0	1,130	0.600	—1,443	—313	—319	1.019
680	52.0	1,470	0.809	—1,947	—477	—483	1.013
690	68.0	1,920	0.991	—2,382	—462	—466	1.008
700	97.0	2,740	1.131	—2,720	20	20	1.004
710	135.0	3,815	1.220	—2,935	880	881	1.001

TABLE 18—RESULTANT OF GAS-PRESSURE AND INERTIA FORCES ALONG CONNECTING-ROD AXES OF A WRIGHT R-1750 ENGINE WITH RESPECT TO CYLINDER NO. 1 WITH ENGINE FIRING

Crank Angle of Cylinder No. 1, Deg.	Cylinder Nos. 1	2	3	4	5	6	7	8	9
0	3,072	—1,954	618	1,615	1,826	2,062	1,470	4,122	—2,087
10	6,682	—2,404	238	1,403	1,830	1,891	1,630	3,980	—1,612
20	9,759	—2,748	—84	1,100	1,815	1,861	1,726	3,908	—1,080
30	8,990	—2,963	—319	706	1,782	1,863	1,776	3,740	—526
40	7,100	—3,036	—483	233	1,656	1,867	1,802	3,480	11
50	5,842	—2,969	—466	—304	1,496	1,859	1,803	3,122	499
60	4,988	—2,785	20	—868	1,250	1,825	1,812	2,735	910
70	4,430	—2,481	881	—1,436	972	1,754	1,817	2,510	1,235
80	4,122	—2,087	3,072	—1,954	618	1,615	1,826	2,062	1,470

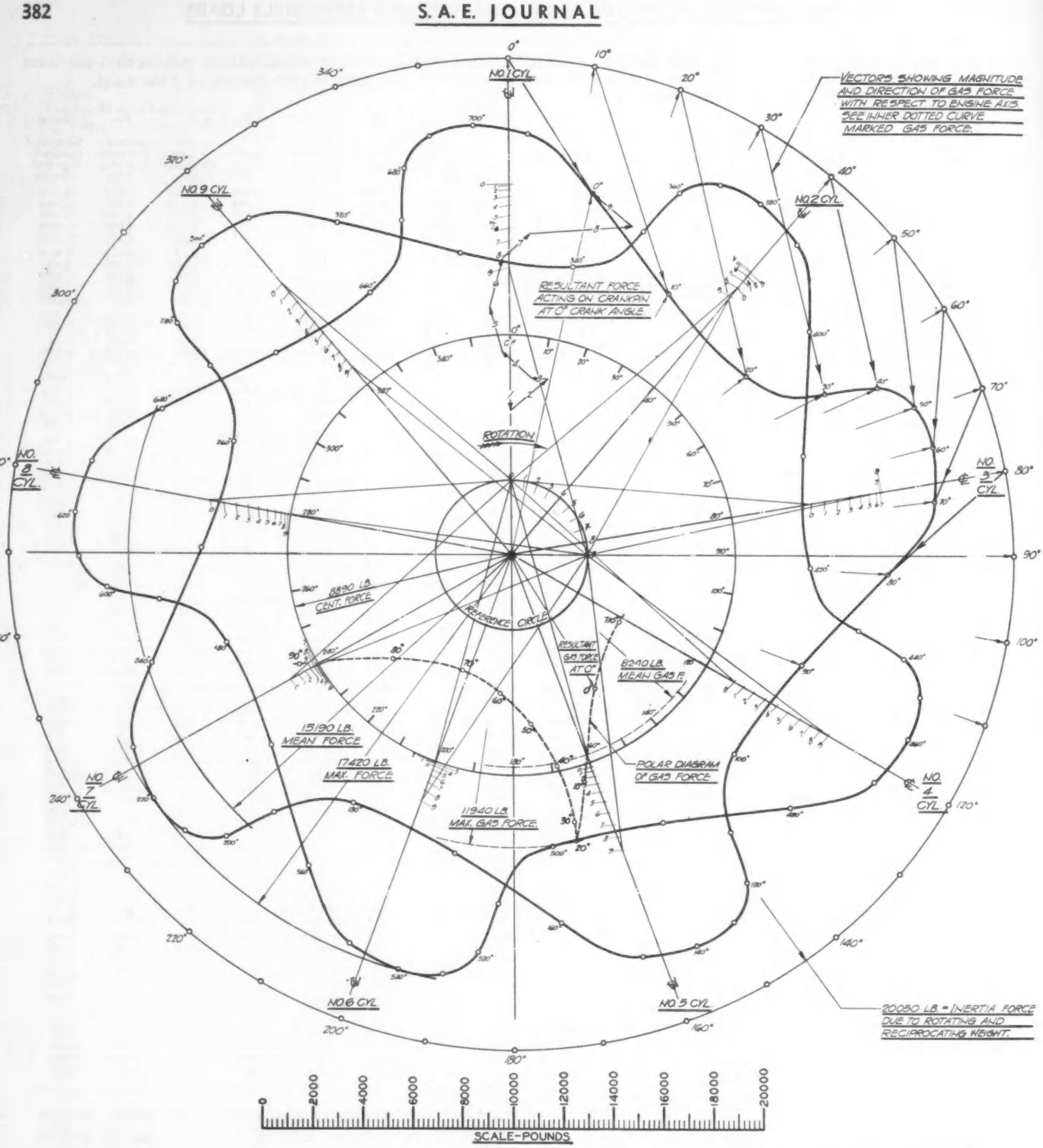


FIG. 20—POLAR DIAGRAM SHOWING THE MAGNITUDE OF THE FORCE ACTING ON THE CRANKPIN OF THE WRIGHT R-1750 CYCLONE ENGINE

This Engine Which Is a Nine-Cylinder Radial-Type Is Rated at 525 Hp. at 1900 R.P.M.

Graphical Layout of Forces.—The force diagram, Fig. 20, is started by drawing cylinder centerlines; then the circle representing centrifugal force acting on the crankpin can be laid out to some convenient scale, say 1000 or 2000 lb. per in. The latter is divided into 10-deg. intervals to show crank positions. Since this circle will be relatively large, a smaller reference circle is drawn about the same center. The first 80 deg. of this reference circle, in the direction of rotation, is also divided into 10-deg. intervals. The equivalent connecting-rod length is found by multiplying the reference-circle radius by L/R for the actual engine. (See Table 13).

Crank positions around the reference circle are numbered consecutively, as 0, 1, 2, 3 and so on. All connecting-rod axes can be considered as passing through

the crankpin center with small error. With compass point on 0, 1, 2, 3 and so on of the reference circle and a radius equal to the equivalent rod-length previously found, corresponding piston-positions are marked along all cylinder axes as shown. By this construction, directions of all connecting-rods are determined for crank angles from 0 to 80 deg. or for points from 0 to 8 inclusive with respect to the reference circle. The resultant force acting on the crankpin, at any given crank-angle, is equal to the centrifugal force plus the vector sum of the resultant force along each rod-axis at the crank angle considered. As for the V-engine, a plus force denotes one producing compression in the connecting-rod, whereas a minus force is considered as producing tension. The vectors that represent, both in magnitude and direction, force along each rod-axis can be numbered the same as corresponding cylinders. Hence, to determine resultant force on the crankpin for 0-deg. crank-angle, start at the point marked 0 deg. on the centrifugal-force circle and draw vector 1 parallel to rod 1, its magnitude being obtained from Table 18. Then from the terminal of 1 draw vector 2 parallel to rod 2 and so on, until the forces along all of the rods have been taken into account. The terminal of vector 9 marked 0 deg. is the resultant force desired. This procedure is carried out in order, starting in each case at points 10, 20, 30 deg. and so forth on the centrifugal-force circle until the resultant force acting on the crankpin is determined through the first 80 deg. of crank rotation. A smooth curve is then drawn through points thus found to show the extent of force variation on the crankpin. In Fig. 20 it is reproduced at 80-deg. intervals throughout two revolutions of the crankshaft so as to complete the diagram.

The maximum resultant-force acting on the crankpin is scaled directly from the diagram and found to be 17,420 lb. The mean or average force is found by first plotting the force versus the crank angle as in Fig. 21 after which the mean height of the curve can be found by a planimeter and this is, of course, the mean force to the scale chosen. The mean resultant-force is found to be 15,190 lb.

Maximum unit-bearing pressure

$$p_m = 17.420/11.58$$
$$= 1505 \text{ lb per sq. in.}$$

Mean unit-bearing pressure

$$p_a = 15,190/11.58$$
$$= 1212 \text{ lb. per sq. in.}$$

Rubbing factor

$$pv = 1312\ [(\pi \times 3.25 \times 1900)/(12 \times 60)]$$
$$= 35,400 \text{ lb-ft. per sec.}$$

Inertia Force Due to Reciprocating Parts of Engine.—The resultant force along connecting-rod axes, due to inertia force only, was arranged as in Table 19, with reference to crank positions of No. 1 cylinder. These values are taken directly from Table 15, by noting that when connecting-rod No. 1 is at top dead-center, or at 0 deg., the following cyclic relation of inertia forces

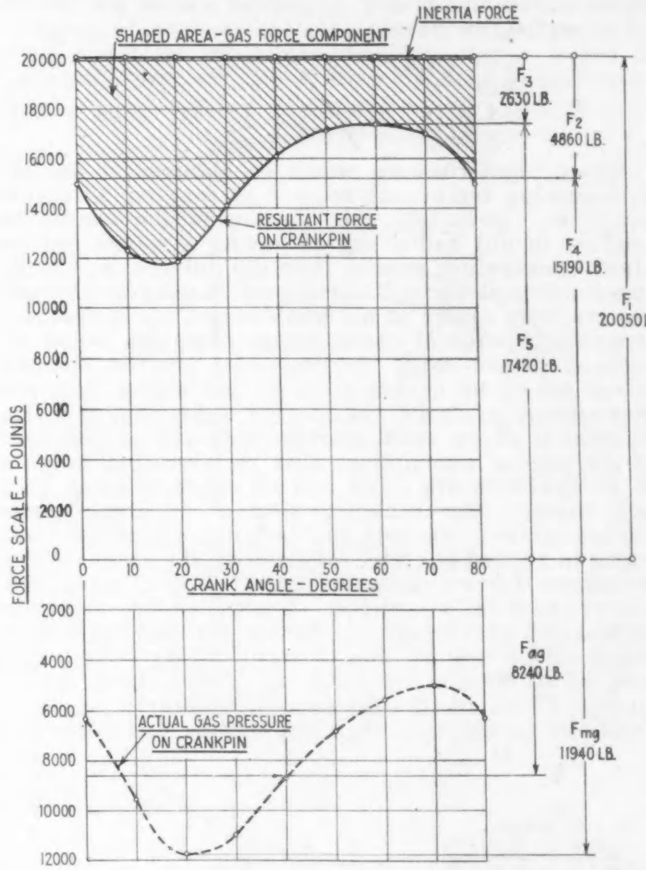


FIG. 21—GAS-PRESSURE, INERTIA AND RESULTANT FORCES ACTING ON THE CRANKPIN OF A WRIGHT R-1750 ENGINE PLOTTED VERSUS THE CRANK ANGLE

exists in the various cylinders: No. 1 is at 0 deg., No. 2 is at 320 deg., No. 3 is at 280 deg., No. 4 is at 240 deg., No. 5 is at 200 deg., No. 6 is at 160 deg., No. 7 is at 120 deg., No. 8 is at 80 deg. and No. 9 is at 40 deg. For purposes of analysis, the reciprocating weight of all cylinders has been assumed as being identical, 6.82 lb.; therefore, a variation in either the direction or magnitude of the resultant inertia-force, if found to exist, would take place in a crank interval not greater than (360/9) or 40 deg. Accordingly, the resultant inertia-force due to reciprocating parts of the engine was determined graphically throughout this range. The resultant force was found to be of constant magnitude, 11,160 lb., acting directly outward along the crank-throw axis. The total resultant inertia-force due to rotating weight at the crankpin and all reciprocating parts, such as pistons, rod ends and the like, is, therefore, 8890 + 11,160 = 20,050 lb. This force is represented by the outer circle of Fig. 20, where 10-deg. crank-intervals are also given. Apparently an exact calculation of this force is obtained for five, seven and nine-cylinder engines by using the following equation:

$$F_1 = 28.4 \times 10^{-6}\ R\ N^2\ (W_c + K_1 W_i)$$

F.S.

where

F_1 = resultant inertia-force due to rotating weight at the crankpin and all reciprocating parts in pounds

$K_1 = \frac{1}{2} + \frac{1}{4}\ (R/L)^2$

N = engine speed

R = radius of crank in inches

R/L = ratio of radius of crank to connecting-rod length

W_c = rotating weight per crankpin in pounds

W_i = reciprocating weight per crankpin in pounds

TABLE 19—RESULTANT INERTIA-FORCE ALONG CONNECTING-ROD AXES OF A WRIGHT R-1750 ENGINE WITH RESPECT TO CYLINDER NO. 1

Cylinder No.	Crank Angle of Cylinder No. 1, Deg. 0	10	20	30	40
1	—3,008	—2,938	—2,730	—2,400	—1,970
2	—1,970	—2,400	—2,730	—2,938	—3,008
3	152	—373	—925	—1,470	—1,970
4	1,540	1,320	1,018	622	152
5	1,810	1,795	1,760	1,680	1,540
6	1,810	1,806	1,804	1,806	1,810
7	1,540	1,680	1,760	1,795	1,810
8	152	622	1,018	1,320	1,540
9	—1,970	—1,470	—925	—373	152

Substituting the proper numerical values for the R-1750 engine, we have

$$K_1 = \tfrac{1}{2} + \tfrac{1}{4}\,(\tfrac{1}{4})^2$$
$$= 0.516$$
$$F_1 = 28.4 \times 10^{-6} \times 3.4375 \times (1900)^2\,(25.22 + 0.516 \times 61.38) = 20{,}050 \text{ lb.}$$

Exact counterbalance would be obtained if the engine-shaking force were reduced to zero for all crank-positions. Obviously, this ideal condition cannot be realized in any radial engine having a master-rod reciprocating-weight greater than the link-rod reciprocating-weight and whose link-rod axes do not pass through the crankpin center at all crank-angles. A comprehensive investigation of radial-engine balancing would involve a rather exact determination of the shaking forces set up by moving parts of the engine, but, for the present analysis, considering balancing only insofar as it affects main-bearing loads will be sufficient. If the present assumptions that reciprocating weights of all cylinders are equal and all connecting-rod axes pass through the crankpin center at all crank-angles are maintained, one-half the reciprocating weight per crankpin applied at crank radius gives the correct counterbalance for reciprocating parts of five, seven and nine-cylinder radial-engines. A proof of this has been worked out graphically by finding the resultant force acting on the engine, due to reciprocating parts only, that is, adding the crankpin and piston side-pressure forces. These inertia forces can, of course, be combined, by considering their magnitude and direction

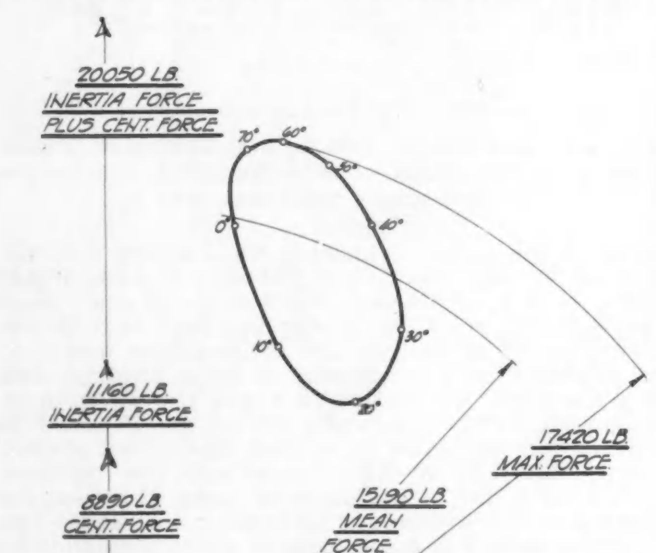


FIG. 22—POLAR DIAGRAM SHOWING THE MAGNITUDE OF THE FORCE ON THE CRANKPIN OF A WRIGHT R-1750 ENGINE AND ITS DIRECTION WITH RESPECT TO THE CRANK THROW

along the cylinder axes, when the same result will be obtained.

Resultant Gas-Force on Main Bearings.—A consideration of the equation given for the inertia force due to the reciprocating parts of the engine and the requirements for balance makes clear the fact that not all of the engine-inertia force is cancelled at the main bearings when counterweights are added. A small but definite force still exists which always acts radially outward along the crank-throw axis, with a constant magnitude of

$$F_u = 28.4 \times 10^{-6}\,RN^2 \times \tfrac{1}{4}\,(R/L)^2\,W_t$$

where the symbols have the same significance as in the other equation. Hence, by substituting the proper values for the R-1750 engine, we have

$$F_u = 28.4 \times 10^{-6} \times 3.4375 \times (1900)^2 \times 0.016 \times 61.38$$
$$= 346 \text{ lb. (349 lb. determined graphically)}$$

Force F_u is developed at the crankpin and main bearings; while an equal and opposite reaction is set up by the resultant piston side-pressure, due to inertia only.

Resultant gas-force acting on the crankpin is represented in Fig. 20 by vectors that have their origin at points marked 0 deg., 10 deg., 20 deg. and so forth on the outer circle of total inertia-force, and terminating at points 0, 10, 20 deg. and so forth on the resultant-force curve. A polar diagram of gas force is constructed by transferring these vectors so that their origin is at the center of the diagram. Gas force is plotted versus crank angle as in Fig. 21. The maximum resultant gas-force acting on the crankpin is found to be 11,940 lb. and the mean, 8240 lb.

Resultant force acting on the main bearings is determined by adding F_u to the resultant gas-force graphically. Force F_u opposes the gas force and has the effect of reducing main-bearing loads by 1 or 2 per cent at ordinary running-speeds. Separate diagrams of force on the main bearings are not given, but for practical purposes, these can be considered as being represented by the resultant gas-force curves. The maximum load acting on the main bearings is found to be 11,700 lb. and the mean, 8000 lb. A fair assumption is that each main-bearing carries one-half the load, which would give a maximum of 5850 lb. and a mean of 4000 lb. acting on each main-bearing at 1900 r.p.m. For the front main-bearing (see Table 13) we have the following values:

Maximum unit-bearing pressure

$$p_m = 5850/7.38$$
$$= 793 \text{ lb. per sq. in.}$$

Mean unit-bearing pressure

$$p_a = 4000/7.38$$
$$= 542 \text{ lb. per sq. in.}$$

Rubbing factor

$$pv = 542\,[\pi \times 4.375 \times 1900)/(12 \times 60)]$$
$$= 19{,}700 \text{ lb-ft. per sec.}$$

For the rear main-bearing the maximum load is 5850 lb. and the mean load is 4000 lb.

The Hoffman roller bearing employed in this engine is of the R type, light series No. R-190-LL, which has a catalog load-rating of 3230 lb. at 2000 r.p.m. The mean load is found to exceed the rated load by 24 per cent, whereas the maximum load exceeds it by about 80 per cent.

The thrust for the front thrust-bearing can be computed from the following equation:

$$T = (375 \times \text{b.hp.} \times e_p)/s$$

where

b.hp. = brake horsepower
e_p = propeller efficiency
s = speed of airplane in miles per hour
T = thrust in pounds

By substitution we obtain for the R-1750 engine

$$T = (375 \times 525 \times 0.75)/130$$
$$= 1140 \text{ lb. approximately}$$

The front thrust-bearing of this engine is a commercial standard S.A.E. light series ball-bearing No. 218. At 2000 r.p.m. this bearing has a rated radial-load capacity of 2540 lb. and a rated thrust-capacity of 50 per cent of the radial load, or 1270 lb., the latter figure agreeing closely with the computed thrust-load.

A polar diagram showing the magnitude of the force acting on the crankpin and its direction with respect to the crank throw is shown in Fig. 22. As explained for the V-engine, the making of this diagram is a necessary step, preceding construction of the comparative wear diagram as shown in Fig. 23. From the latter we see that the oil hole is most favorably located with regard to entry of oil into the bearing. Furthermore, this diagram can be considered as typical of any nine-cylinder radial-engine at full load.

This engine has been given prolonged running-tests, after which it was dissassembled and inspected. All bearings were found to be in excellent condition, hence we may conclude that an ample factor of safety has been provided for the service required.

Analytical Method for Estimating Bearing Loads of Aircraft Engines

The principal factors to be considered for design purposes are

(1) Maximum unit bearing-pressure
(2) Mean unit bearing-pressure
(3) Rubbing or *pv* factor in pounds per square inch times feet per second

Construction of proper diagrams is a laborious process and usually requires considerably more time than a designer feels justified in spending on this phase of his engine design. Although an analytical method for approximating bearing loads is empirical, it has the advantage of simplicity and rapidity in application. The mean inertia-force acting on a bearing can be computed to a satisfactory degree of accuracy. Gas pressures are assumed to vary directly in proportion to the piston area and brake mean effective pressure of the engine, which is very nearly true for compression-ratios between 5.0:1 and 6.0:1. In the analytical method of analysis, effects of gas pressure are taken into account by suitable constants. In Table 20, bearing loads derived analytically are compared with those obtained by the usual graphic method; the results obtained are seen to vary somewhat with the proportion of mean inertia-force to gas-pressure force and the number of pistons operating on one crankpin. The best results with this method of analysis are obtained for radial engines of nine cylinders where the maximum error should not exceed 5 per cent. For other cylinder arrangements,

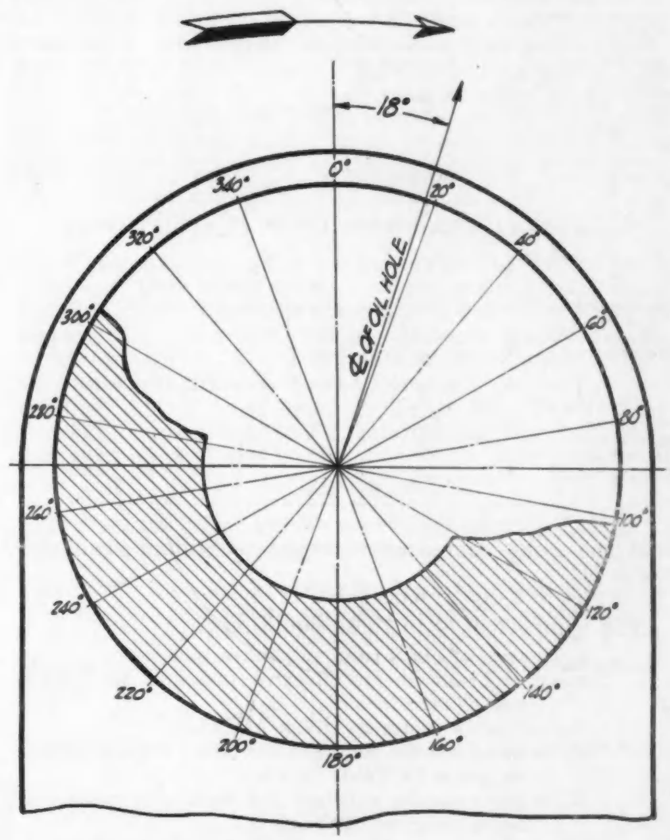


FIG. 23—DIAGRAM OF COMPARATIVE WEAR ON THE CRANKPIN OF A WRIGHT R-1750 ENGINE

the degree of accuracy is sufficient for practical design purposes. A brief outline of this method follows.

Analysis of Crankpin-Bearing Loads.—The mean inertia-force acting on the crankpin is

$$F_1 = 28.4 \times 10^{-6} RN^2 (W_c + K_1 W_i)$$

The gas pressure component of the mean crankpin-force is

$$F_2 = K_2 A_p \times \text{b.m.e.p.}$$

TABLE 20—COMPARISON OF RESULTS OBTAINED BY GRAPHIC AND ANALYTIC METHODS OF THE FORCES ACTING ON THE BEARINGS OF 12-CYLINDER AIRCRAFT ENGINES

Engine	Curtiss D-12 Modified		Liberty 12 Water-Cooled		Liberty 12 Air-Cooled		Liberty 12 Air-Cooled		1200-Hp. 12-Cylinder 60-Deg. V-Type with 7½-In. Bore and 7¾-In. Stroke [a]		Packard 2500 Water-Cooled	
Speed, r.p.m.	2,800		1,700		1,900		2,100		1,800		2,000	
Method	Analytic	Graphic	Analytic	Graphic	Analytic	Graphic	Analytic	Graphic	Analytic	Graphic	Analytic	Graphic
Crankpin												
Mean	5,710	5,330	3,960	3,900	3,930	3,795	4,770	4,490	9,930	10,300	6,540	6,795
Maximum	6,960	6,960	5,560	5,380	5,300	5,150	6,140	5,960	13,900	14,400	9,330	10,940
End Main												
Mean	3,885	3,770	2,840	2,660	3,125	3,070	3,800	3,680	7,025	7,155	4,380	4,370
Maximum	4,660	4,740	3,760	3,610	3,975	3,910	4,690	4,630	9,310	9,080	5,935	5,735
Intermediate Main												
Mean	4,085	3,995	3,005	3,075	3,350	3,350	4,075	3,925	7,430	8,090	4,605	5,155
Maximum	5,925	5,800	5,345	4,900	5,360	4,880	6,085	5,710	13,190	13,460	8,700	9,370
Center Main												
Mean	8,000	7,385	5,200	4,975	6,000	5,970	7,450	7,270	12,840	13,300	7,780	7,945
Maximum	9,060	8,950	7,130	6,750	7,660	7,480	9,110	8,930	17,610	17,000	11,160	10,550
Centrifugal Force, Cheek and One-Half of Pin	1,230		1,020		1,380		1,685		2,450		1,325	

[a] Data obtained from design study of a large water-cooled engine.

TABLE 21—INERTIA AND GAS-PRESSURE FACTORS FOR CRANK-PIN-BEARING LOADS

Cylinders per Crankpin and Arrangement	Engine	K_1	K_2	K_3
Single Vertical	Liberty 6	0.56	0.080	1.25
Two 60-Deg. V (also 45-Deg. V)	Curtiss V-1570	0.56	0.065	0.75
Two 90-Deg. V	Hispano 300	0.54	0.200	1.40
Three 40-Deg. W	U.S.A. W-1	0.54	—0.180	0.76
Three 60-Deg. W	Napier Lion	0.54	0.170	1.60
Three 80-Deg. W	U.S.A. W3 (Proposed)	0.54	0.060	0.72
Three Radial		0.53	—0.140	0.82
Five Radial		0.52	—0.640	0.20
Seven Radial		0.52	—1.010	—0.38
Nine Radial	Wright R-1750	0.52	—1.390	—0.76

TABLE 22—DATA ON CURTISS D-12F (V-1150F) ENGINE

Bore of Cylinder, in.	4½
Stroke, in.	6
Piston Area, A_p, sq. in.	15.9
Brake Mean Effective Pressure, b.m.e.p., lb. per sq. in.	130.5
$A_p \times$ b.m.e.p.	2,080
Rotating Weight at Crankpin, lb.	4.32
Reciprocating Weight per Crankpin, lb	6.42

Bearing	Diameter, In.	Effective Length, In.	Projected Area, Sq. In.
Crankpin	2.5	1.812	4.54
End Main	3.0	1.562	4.69
Intermediate Main	3.0	1.562	4.69
Center Main	3.0	1.812	5.44

and the same component for the maximum crankpin-force is

$$F_3 = K_3A_p \times \text{b.m.e.p.}$$

The symbols used in these equations are

A_p = area of one piston in square inches
b.m.e.p. = brake mean effective pressure in pounds per square inch
K_1 = inertia factor as given in Table 21
K_2 = gas-pressure constant for mean crankpin-force as given in Table 21
K_3 = gas-pressure constant for maximum crankpin-force as given in Table 21
N = engine speed in revolutions per minute
R = radius of crank in inches
W_c = rotating weight at crankpin in pounds
W_i = reciprocating weight per crankpin in pounds

The mean force due to both gas pressure and inertia acting on the crankpin is $F_4 = F_1 + F_2$ and the maximum force, $F_5 = F_1 + F_3$. Let

A = projected area of crankpin bearing
d = diameter of crankpin in inches
N = engine speed in revolutions per minute
p_a = mean or average unit bearing-pressure
p_m = maximum unit bearing-pressure
pv = rubbing factor in pounds per square inch times feet per second

Then

$$p_a = F_4/A$$
$$p_m = F_5/A$$
$$pv = p_a\,[(\pi dN)/(12/60)]$$

Values of inertia and gas-pressure constants K_1, K_2 and K_3 have been worked out from graphic analyses of several engines and are given in Table 21. These constants are dependent mainly on the cylinder arrangement as would be expected, hence the engine from which they are derived is also given.

Main Bearings of 12-Cylinder 45 or 60-Deg. V-Engine.—Main-bearing gas-pressure and inertia factors for 12-cylinder 45 or 60-deg. V-engines are as follows: $K_4 = 0.84$, $K_5 = 0.96$, $K_6 = 0.035$, $K_7 = 1.04$, $K_8 = -0.28$ and $K_9 = 0.55$.

End Main-Bearing.—Let F_6 equal centrifugal force of one-half crankpin and one crank cheek. Then the mean or average inertia-force acting on the end main-bearing is closely approximated by $F_7 = (F_1/2) + F_6$; likewise, the mean force due to both gas pressure and inertia, by $F_8 = (F_4/2) + K_4F_6$ and the maximum force, by $F_9 = (F_5/2) + K_5F_6$, where K_4 and K_5 are empirical constants to take into account the direction of vector force F_6, which is to be added. After forces F_8 and F_9 have been computed, unit bearing-pressures and the pv factor can be obtained as for the crankpin.

Intermediate Main-Bearings.—Mean inertia-force is the same as for end main-bearings, that is, $F_7 = (F_1/2) + F_6$. However, if the customary firing order of American 12-cylinder V-type engines is followed, gas pressures acting will differ in phase by 240 deg. (see Fig. 9), hence the mean force due to both gas pressure and inertia can be represented by $F_{10} = F_7 + K_6A_p \times$ b.m.e.p. Also maximum force $F_{11} = F_7 + K_7A_p \times$ b.m.e.p., where K_6 and K_7 are gas-pressure factors. Using forces F_{10} and F_{11}, unit bearing-pressures and the pv factor can now be determined.

Center Main-Bearing.—Mean inertia-force equals $2F_7$, since both crankpins adjacent to the center bearing are in line (see Fig. 9), but gas pressures now differ in phase by 360 deg. so that mean force acting on the center bearing is $F_{12} = 2F_7 + K_8A_p \times$ b.m.e.p. and the maximum force $F_{13} = 2F_7 + K_9A_p \times$ b.m.e.p. Forces F_{12} and F_{13} can now be used to determine unit bearing-pressures and the pv factor.

Graphic analyses for a number of 12-cylinder V-engines are available and forces obtained by this method are compared with those obtained by the analytical method in Table 20. The degree of accuracy attained is apparent from this table. As a further means of illustrating the use of this method, complete analyses will be given for a modern 12-cylinder 60-deg. V-engine, also for a nine-cylinder radial.

Bearing Analysis for a 12-Cylinder 60-Deg. V-Engine.—In making this analysis a Curtiss D-12F (V-1150F) engine rated at 430 b.hp. at 2300 r.p.m. was used. Data on this engine are given in Table 22.

Bearing Analysis for 2300 R.P.M.—Substituting the corresponding numerical values from Table 22 in the equations already derived for the various forces acting on a crank-pin bearing, we obtain

$$F_1 = 28.4 \times 10^{-6} \times 3.0 \times (2300)^2\,(4.32 + 0.56 \times 6.42)$$
$$= 3560 \text{ lb.}$$
$$F_2 = 0.065 \times 15.9 \times 130.5$$
$$= 135 \text{ lb.}$$
$$F_3 = 0.75 \times 2080$$
$$= 1560 \text{ lb.}$$
$$F_4 = 3560 + 135$$
$$= 3695 \text{ lb.}$$
$$F_5 = 3560 + 1560$$
$$= 5120 \text{ lb.}$$
$$p_a = 3695/4.54$$
$$= 814 \text{ lb. per sq. in.}$$
$$p_m = 5120/4.54$$
$$= 1130 \text{ lb. per sq. in.}$$
$$pv = 814 \times [(\pi \times 2.5 \times 2300)/(12 \times 60)]$$
$$= 20{,}400 \text{ lb-ft. per sec.}$$

Following a similar procedure for the end main-bearing, we have a value for the centrifugal force of one-half of the crankpin of

$$28.4 \times 10^{-6} \times 0.655 \times 3.0 \times (2300)^2 = 295 \text{ lb.}$$

and

$$28.4 \times 10^{-6} \times 2.68 \times 1.33 \times (2300)^2 = 535 \text{ lb.}$$

for that of one crank cheek, which gives a value for F_6 or the total centrifugal force of 830 lb. Substituting in the remaining equations we obtain the following values:

$$F_7 = 3560/2 + 830$$
$$= 2610 \text{ lb.}$$
$$F_8 = 3695/2 + 0.84 \times 830$$
$$= 2545 \text{ lb.}$$
$$F_9 = 5120/2 + 0.96 \times 830$$
$$= 3360 \text{ lb.}$$

$$p_a = 2545/4.69 = 543 \text{ lb. per sq. in.}$$

and

$$p_m = 3360/4.69 = 717 \text{ lb. per sq. in.}$$

$$pv = 543 \times [(\pi \times 3.0 \times 2300)/(12 \times 60)] = 16{,}350 \text{ lb-ft. per sec.}$$

Values obtained in the same way for the intermediate main-bearing are

Mean inertia-force $F_7 = 2610$ lb.

$$F_{10} = 2610 + 0.035 \times 2080 = 2685 \text{ lb.}$$

$$F_{11} = 2610 + 1.04 \times 2080 = 4770 \text{ lb.}$$

$$p_a = 2685/4.69 = 573 \text{ lb. per sq. in.}$$

$$p_m = 4770/4.69 = 1020 \text{ lb. per sq. in.}$$

$$pv = 573 \times [(\pi \times 3.0 \times 2300)/(12 \times 60)] = 17{,}250 \text{ lb-ft. per sec.}$$

For the force acting on the center main-bearing we obtain the following:

Mean inertia-force

$$= 2F_7 = 2 \times 2610 = 5220 \text{ lb.}$$

$$F_{12} = 5220 - (0.28 \times 2080) = 4640 \text{ lb.}$$

$$F_{13} = 5220 + (0.55 \times 2080) = 6365 \text{ lb.}$$

$$p_a = 4640/5.44 = 854 \text{ lb. per sq. in.}$$

$$p_m = 6365/5.44 = 1170 \text{ lb. per sq. in.}$$

$$pv = 854 \times [(\pi \times 3.0 \times 2300)/(12 \times 60)] = 25{,}700 \text{ lb-ft. per sec.}$$

Several Air Service pilots have estimated that the D-12 (V-1150) engine may attain a speed of 3500 r.p.m. during violent maneuvers, such as a power dive from great altitudes. No evidence of this extremely high speed being particularly destructive to the engine bearings has been found; consequently, bearing loads for this speed have been estimated by the analytical method, and results arrived at should be of interest. The brake mean effective pressure for this speed was assumed to be 90 lb. per sq. in. The results of this analysis are presented in Table 23. In this connection, it may be recalled that the Curtiss D-12 (V-1150) crankpin and main bearings are steel backed, babbitt lined and not high-lead bronze.

Bearing Analysis for a Nine-Cylinder Air-Cooled Radial-Engine.—In this analysis a Pratt & Whitney Wasp R-1340 engine rated at 430 b.hp. at 2100 r.p.m. was used. Data on this engine are given in Table 24.

Bearing Analysis for 2100 R.P.M.—Substituting the corresponding numerical values from Table 24 in the equations already derived for the various forces acting on a crankpin bearing, we obtain

$$F_1 = 28.4 \times 10^{-6} \times 2.875 \times (2100)^2 \; (19.8 + 0.52 \times 56.5) = 17{,}700 \text{ lb.}$$

$$F_2 = -1.39 \times 3275 = -4550 \text{ lb.}$$

$$F_3 = -0.76 \times 3275 = -2490 \text{ lb.}$$

$$F_4 = 17{,}700 - 4550 = 13{,}150 \text{ lb.}$$

$$F_5 = 17{,}700 - 2490 = 15{,}210 \text{ lb.}$$

$$p_a = 13{,}150/8.85 = 1488 \text{ lb. per sq. in.}$$

$$p_m = 15{,}210/8.85 = 1720 \text{ lb. per sq. in.}$$

$$pv = 1488 \times [(\pi \times 2.625 \times 2100)/(12 \times 60)] = 35{,}800 \text{ lb-ft. per sec.}$$

Main Bearings.—Main bearings of radial engines that have one crank-throw are generally of the anti-friction type, balls or rollers being employed. Engines of this type are counterbalanced; that is, counterweights are applied to extensions of the crank cheeks as shown in Fig. 22. The mass of these counterweights is carefully determined, and, for bearing-analysis purposes, an engine with five or more cylinders can be considered as being, as a whole, exactly balanced. However, in connection with the graphic method of analysis, we have shown that a small unbalanced force F_u is applied to the crankpin and thence to the main bearings, although the latter are loaded principally by the resultant gas-force, because all resultant engine-inertia forces are cancelled except F_u. The latter force opposes the resultant gas-force in engines of five or more cylinders, thereby effecting a slight reduction in main-bearing loads at normal operating speeds. In Figs. 20 and 21, the mean resultant gas-force is denoted by F_{ag} which equals $K_{10}A_p \times$ b.m.e.p. and the maximum, by F_{mg}, which equals $K_{11}A_p \times$ b.m.e.p. Gas-pressure factors K_{10} and K_{11} are listed in Table 25. The inertia-force component due to F_u, as affecting the mean load, can be computed as follows:

$$F_{14} = 28.4 \times 10^{-6}\, RN^2 \; (K_{12}W_i)$$

Likewise, its effect on the maximum bearing-load is

$$F_{15} = 28.4 \times 10^{-6}\, RN^2 \; (K_{13}W_i)$$

where K_{12} and K_{13} are inertia factors, from Table 25. The main-bearing load can be considered as equally divided between the two bearings adjacent to the crank-throw. The average or mean load applied to each main-bearing is

$$F_{16} = (F_{ag} + F_{14})/2$$

and the maximum load applied to each main-bearing is

$$F_{17} = (F_{mg} + F_{15})/2$$

Hence, for the R-1340, we have

$$F_{ag} = 2.33 \times 3275 = 7640 \text{ lb.}$$

$$F_{mg} = 3.38 \times 3275 = 11{,}070 \text{ lb.}$$

$$F_{14} = 28.4 \times 10^{-6} \times 2.875 \times (2100)^2 \; (-0.011 \times 56.5) = -220 \text{ lb.}$$

$$F_{15} = 28.4 \times 10^{-6} \times 2.875 \times (2100)^2 \; (-0.011 \times 56.5) = -220 \text{ lb.}$$

TABLE 23—RESULTS OF BEARING ANALYSIS OF THE CURTISS D-12 (V-1150) ENGINE AT A SPEED OF 3500 R.P.M.

Bearing	p_a, Lb. per Sq. In.	p_m, Lb. per Sq. In.	pv, Lb-Ft. per Sec.
Crankpin	1,837	2,070	70,000
End Main	1,235	1,395	56,600
Intermediate Main	1,300	1,610	59,600
Center Main	2,150	2,360	98,500

TABLE 24—DATA ON PRATT & WHITNEY WASP R-1340 ENGINE

Bore, in.	5.750
Stroke, in.	5.750
Piston Area, A_p, sq. in.	26.0
Brake Mean Effective Pressure, b.m.e.p., lb. per sq. in.	126
$A_p \times$ b.m.e.p.	3,275
Rotating Weight at Crankpin, lb.	19.8
Reciprocating Weight per Crankpin, lb.	56.5
Crankpin Diameter, in.	2.625
Effective Length of Crankpin Bearing, in.	3.375
Projected Area, sq. in.	8.85

TABLE 25—INERTIA AND GAS-PRESSURE FACTORS FOR MAIN BEARINGS OF RADIAL ENGINES

No. of Cylinders	K_{10}	K_{11}	K_{12}	K_{13}
3	1.16	3.52	0.032	−0.167
5	1.50	3.60	−0.010	−0.014
7	1.82	3.26	−0.013	−0.014
9	2.33	3.38	−0.011	−0.011

TABLE 26—COMPARISON OF CRANKPIN-BEARING LOADS WITH VARIOUS ARRANGEMENTS OF 6-IN. BORE AND 6⅞-IN. STROKE CYLINDERS OBTAINED BY THE ANALYTIC METHOD

Cylinders Per Crankpin	Arrangement	Displacement, Cu. In.	Weight per Crankpin, Lb. Rotating	Weight per Crankpin, Lb. Reciprocating	Force, Lb. Maximum	Force, Lb. Mean	Force per Cu. In. of Piston Displacement, Lb. Maximum	Force per Cu. In. of Piston Displacement, Lb. Mean	Required Bearing Area Based on Mean Load, Per Cent
Single		195	6.00	6.82	7,880	3,740	40.4	19.2	100
Two	60-Deg. or 45-Deg. V	390	8.00	13.64	8,140	5,730	20.9	14.7	153
Three	40-Deg. W	585	10.00	20.46	10,100	6,790	17.3	11.6	181
Three	60-Deg. W	585	10.00	20.46	13,050	8,020	22.3	13.7	214
Three	80-Deg. W	585	10.00	20.46	9,960	7,630	17.0	13.0	204
Three	Radial	585	10.00	20.46	10,230	6,860	17.5	11.7	183
Five	Radial	975	14.00	34.10	11,880	8,920	12.2	9.2	238
Seven	Radial	1,365	18.00	47.74	13,740	11,520	10.1	8.5	308
Nine	Radial	1,755	22.00	61.38	16,320	14,080	9.3	8.0	376

TABLE 27—CRANKPIN-BEARING LOADS AND pv VALUES OF AIRCRAFT ENGINES

Engine	Cylinders No.	Cylinders Bore, In.	Cylinders Stroke, In.	Rated Power, B. Hp.	Rated Speed, R.P.M.	Brake Mean Effective Pressure, Lb. per Sq. In.	Bearing Dimensions Diameter, In.	Bearing Dimensions Effective Length, In.	Net Projected Area, Sq. In.	Weight, Lb. Rotating	Weight, Lb. Average Reciprocating	Unit Pressures, Lb. per Sq. In. p_a Mean	Unit Pressures, Lb. per Sq. In. p_m Maximum	Rubbing Velocity, Ft. per Sec.	p_v Lb-Ft. per Sec.
Curtiss V-1570 Light Shaft Articulated Rods	12	5.125	6.250	437 630	2,000[b] 2,400[c] 3,500[d]	110.5 132.4 80.0	2.500	1.390	3.28	5.360	4.00	1,112 1,585 3,300	1,590 2,154 3,650	21.80 26.20 38.20	24,300 41,500 126,000
Curtiss V-1570 Heavy Shaft Articulated Rods	12	5.125	6.250	437 630	2,000[b] 2,400[c] 3,500[d]	110.5 132.4 80.0	3.000	1.390	4.17	6.180	4.15	957 1,370 2,860	1,330 1,820 3,130	26.20 31.40 45.80	25,100 43,000 131,000
Curtiss V-1570 Heavy Shaft Forked Rods	12	5.125	6.250	437 630	2,000[b] 2,400[c] 3,500[d]	110.5 132.5 80.0	3.000	1.390	4.17	8.500	4.20	1,160 1,660 3,480	1,540 2,110 3,750	26.20 31.40 45.80	30,400 52,200 159,000
Curtiss V 1150	12	4.500	6.000	435	2,300	130.5	2.500	1.812	4.54	4.320	3.21	814	1,130	25.10	20,400
Maybach	6	6.500	7.090	294	1,400	118.0	2.598	2.663	6.92	5.625	17.35	528	1,696	15.86	8,360
Rausie	6	5.000	6.000	175	1,650	119.0	2.125	2.125	4.52	3.730	5.95	454	1,640	15.30	6,950
Liberty	12	5.000	7.000	420	1,700	119.0	2.375	2.187	5.20	6.300	6.20	750	1,035	17.60	13,200
Packard 2500	12	6.375	6.500	800	2,000	127.5	3.250	2.375	7.72	8.500	7.60	880	1,417	28.37	24,960
Packard 1500	12	5.375	5.500	510	2,100	128.5	2.500	2.375	5.94	6.000	5.00	748	1,410	22.92	17,150
Napier Lion W	12	5.500	5.125	490	2,000	122.0	2.750	2.625	7.22	6.400	5.50	683	1,273	23.10	15,770
U.S.A. W-1-A	18	5.500	6.500	800	1,800	126.8	3.000	2.437	7.31	11.200	7.40	872	1,250	23.50	20,500
Pratt & Whitney R-1340	9	5.750	5.750	246 450	1,800[b] 2,100[c] 3,500[d]	80.5 120.5 60.0	2.625	3.375	8.85	19.800	6.28	1,138 1,488 5,310	1,292 1,720 5,420	20.60 24.05 40.10	23,400 35,800 213,000
Pratt & Whitney R-1860	9	6.250	6.750	567	1,950	123.0	2.875	3.500	10.06	28.180	7.93	1,835	2,072	24.70	44,900
Wright R-1750	9	6.000	6.875	525	1,900	125.0	3.250	3.562	11.58	25.220	6.82	1,312	1,505	26.95	35,400
Wright R-1820	9	6.125	6.875	575	1,900	132.0	3.250	3.625	11.78	26.660	7.04	1,322	1,532	26.96	35,600
Kinner K-5	5	4.250	5.250	110	2,000	117.0	1.875	2.500	4.69	11.050	3.06	982	1,915	16.36	16,070

[b] Cruising speed.
[c] Normal speed.
[d] Diving speed.

TABLE 28—MAIN-BEARING LOADS AND pv VALUES OF AIRCRAFT ENGINES

Engine	Journal Diameter, In.	Rubbing Velocity, Ft. per Sec.	Center Main: Net Projected Area, Sq. In.	Center Main: p_a, Lb. per Sq. In.	Center Main: p_m, Lb. per Sq. In.	Center Main: pv, Lb-Ft. per Sec.	Intermediate Main: Net Projected Area, Sq. In.	Intermediate Main: p_a, Lb. per Sq. In.	Intermediate Main: p_m, Lb. per Sq. In.	Intermediate Main: pv, Lb-Ft. per Sec.	End Main: Net Projected Area, Sq. In.	End Main: p_a, Lb. per Sq. In.	End Main: p_m, Lb. per Sq. In.	End Main: pv, Lb-Ft. per Sec.
Curtiss V-1570 Light Shaft Articulated Rods	3.500	30.50[e] 36.70[f] 53.50[g]	5.39	1,170 1,377 3,140	1,285 1,754 3,400	35,600 50,500 168,000	4.52	644 948 1,933	1,150 1,504 2,300	19,600 34,700 103,500	4.52	605 863 1,810	807 1,112 2,030	18,500 31,600 97,000
Curtiss V-1570 Heavy Shaft Articulated Rods	3.500	30.50[e] 36.70[f] 53.50[g]	5.39	972 1,430 3,260	1,320 1,850 3,520	29,600 52,400 175,000	4.52	668 957 2,010	1,180 1,560 2,380	20,400 35,000 108,000	4.52	630 905 1,900	830 1,150 2,100	19,200 33,200 102,000
Curtiss V-1570 Heavy Shaft Forked Rods	3.500	30.50[e] 36.70[f] 53.50[g]	5.39	1,130 1,658 3,745	1,480 2,070 4,000	34,500 60,600 200,000	4.52	762 1,090 2,410	1,270 1,690 2,660	23,200 39,800 129,000	4.52	725 1,038 2,185	925 1,280 2,400	22,100 38,000 117,000
Curtiss V-1150	3.000	30.10	5.44	854	1,170	25,700	4.69	573	1,020	17,250	4.69	543	716	16,350
Maybach	2.598	15.86	6.20	636	927	10,100	6.20	447	1,236	7,090	6.20	376	846	5,970
Rausie	2.125	15.30	4.52	542	730	8,300	4.52	363	1,010	5,550	4.52	312	730	4,780
Liberty	2.625	19.45	4.27	1,165	1,580	22,650	4.27	720	1,150	14,000	4.27	623	845	12,100
Packard 1500	3.000	27.50	3.56	1,414	1,870	38,900	2.81	1,215	2,370	33,450	3.94	732	931	20,100
Packard 2500	3.500	30.55	8.75	908	1,206	27,750	5.25	982	1,785	30,000	7.88	555	728	16,950
Napier Lion W		Roller Main Bearings												
U.S.A. W-1-A	3.125	24.55	11.23	721	1,015	17,700	6.54	745	1,330	18,300	6.54	654	900	15,750

[e] Cruising speed.
[f] Normal speed.
[g] Diving speed.

Mean force on each main-bearing is

$$F_{16} = (7640 - 220)/2 = 3710 \text{ lb.}$$

and the maximum force is

$$F_{17} = (11,070 - 220)/2 = 5425 \text{ lb.}$$

The front main-bearing of this engine has an outside diameter of 130 mm. and an inside diameter of 75 mm., is 25 mm. wide and has 13 rollers that are 9/16 in. in diameter. This size corresponds with the Hoffman two-lipped, metric-type roller bearing of the light series No. R-175-LL, except that the rollers are increased from ½ to 9/16-in. diameter. The standard bearing with ½-in. rollers has a catalog rating of 2310 lb. at 2000 r.p.m. The rear main-bearing is similar to Hoffman roller bearing No. R-180-LL, except that rollers are also 9/16-in. diameter instead of ½-in. Catalog rating of the standard bearing with ½-in. rollers is 2550 lb. at 2000 r.p.m.

The approximate thrust on the front thrust-bearing of this engine, which is an S.K.F. No. 6216 ball bearing, is $(375 \times 450 \times 0.82)/140 = 990$ lb. This bearing has a catalog rating for radial load of 1560 lb. at 2000 r.p.m.; but the thrust capacity is not given in the S.K.F. catalog. Although the bearing loads of this engine at rated speed and load are found to be rather high, its exceptional record for reliability in service is conclusive proof that the safety factor is satisfactory.

To show clearly the effect of cylinder arrangement of the crankpin load, Table 26 has been prepared. The important point brought out here is that the minimum load per unit of cylinder displacement is obtained with a radial disposition of the cylinders. Crankpin-bearing loads and rubbing factors for various types of aircraft engine are presented in Table 27, the values for the radial engines having been obtained by the analytical method of analysis. Main-bearing loads and rubbing factors for various aircraft engines are given in Table 28 which shows the large variation in bearing-pressures and *pv* factors that is obtained in practice.

BIBLIOGRAPHY

Caminez, H., and C. W. Iseler—Standard Method of Engine Calculations, Air Service Information Circular No. 421. Published by the Government Printing Office, City of Washington.

Devillers, Rene—Automobile and Aero Engines. Published by Spon & Chamberlin, New York City.

Dunkerley, S.—Mechanism. Published by Longmans, Green & Co., New York City.

Farren, W. S.—The Articulated Connecting-Rod—an Alternative Method for Finding Accelerations. *Journal of the Royal Aeronautical Society*, March, 1927, p. 234.

Fearn, E. J.—The Articulated Connecting-Rod. *Journal of the Royal Aeronautical Society*, February, 1927, p. 133.

THE DISCUSSION

CHAIRMAN ARTHUR NUTT[2]:—I notice that in the radial-engine analysis the reciprocating weights of all cylinders are considered as equal and that the connecting-rod axes are assumed to intersect at the crankpin center. I believe that, if we could build all our radial engines under those conditions, we would notice considerable difference in the smoothness because of the slightly unbalanced condition that arises from being compelled to locate the link-rod pins off center. The actual unbalanced condition varies, of course, with the engine, but large engines have an appreciable unbalanced condition, and we can only tell by experience how much we can stand in the way of unbalance.

Use of *pv* Factor Criticized

DR. H. C. DICKINSON[3]:—I want to congratulate the authors on the very ingenious and neat graphic analysis of the problem. Such things are very pleasing although they are very difficult to follow. However, I want to discuss one point in the paper, which is the use of what might be called a conventional *pv* factor as some sort of criterion of the carrying capacity of the bearing. As a matter of fact, the use of that factor was discarded some 15 years ago by turbine makers, electric-motor manufacturers and similar companies, and for a very good reason. The problem itself has been very well analyzed, and I will try to see if I cannot make clear the reasons why the *pv* value is misleading.

In a bearing the oil film is thicker on the one side than on the other, and the difference in that thickness, and the consequent increase in pressure at the thinner point, is the cause for the bearing supporting load. If a bearing rotates slowly, the thickness of the oil film is less, but if it rotates rapidly, the thickness at this point is greater. Therefore the carrying capacity of the bearing, aside from the question of the quantity of heat generated, depends upon the thickness of the oil film at the thin point.

Analysis of the lubrication problem and also a large volume of experimental work have shown that the safety factor, so to speak, can be represented by a formula which we usually write as $(ZN)/p$. That particular formula can just as well be written $(Zv)/p$, because the v being the velocity and N the number of revolutions, one is just as good as the other.

If we plot the friction loss in the bearing against this $(Zv)/p$ factor, we get a straight line that breaks off somewhere near the lower end and this is the point where the bearing goes bad. What the Z and the N and p are makes no difference. The nature of that function is what counts, because leaving out the Z, which is the viscosity of the oil and which is constant for our present purpose, we have the v divided by the p. That is the exact form in which the safety factor appears. It is not pv, but it is v/p. To illustrate what that means, a bearing on a rolling mill would break down absolutely at a *pv* factor somewhere between 500 and 1000. The only use of the *pv* factor is as an indication of the quantity of heat that is generated in the bearing, and we have to take care of that by pumping. It has nothing whatever to do with the load-carrying capacity of the bearing. Consequently I want to protest against the continued use of the *pv* factor as an index of carrying capacity, for it is absolutely misleading when used in that connection.

A MEMBER:—What is the author's opinion on the difference in permissible *pv* factor in automobile and aircraft engines? I have not available the data that the previous discusser has but in automobile practice a definite reason for calculating *pv* factors seems to exist. We do know that we can get away with 30,000 in any engine. When we get up into the high speeds, 40,000 is becoming very dangerous and 60,000 is just about suicidal. The reason for that is that we run into very high automobile-engine temperatures. That may be

[2] M.S.A.E.—Vice-president of engineering, Wright Aeronautical Corp., Paterson, N. J.

[3] M.S.A.E.—Chief of heat and power division, Bureau of Standards, City of Washington.

the answer in the aircraft engine. This *pv* formula assumes constant, continuous film lubrication. In automobile engines we know that we do not get continuous-flow lubrication at high speeds and heavy loads.

DR. DICKINSON:—We know that under anything like normal bearing-conditions we do get continuous film-lubrication. As a matter of fact, we can put an electric-light bulb across the oil film that we use as an insulator and put the light out. That is not absolutely true under conditions where dirt is in the bearing, then we have a certain degree of bridging over by the particles of dirt; but the very fact that a bearing can be run for a billion revolutions, let us say, without any measurable wear, shows conclusively in itself that no metallic contact of any consequence exists.

Author's Reply to Criticisms

FORD L. PRESCOTT:—Mr. Nutt brought up the question of extending the link rods to the center of crankpin. That was done in this analysis merely to save time. One man at Wright Field consumed about 9 months' time in making an exact analysis of a nine-cylinder radial-engine and, when he finished, it was no more accurate than this simple method by which an ordinary draftsman can make the whole diagram in 2 or 3 days. Of course, if we could extend all the rods to the crankpin center, we might get better balance in our engines, but we have secured very satisfactory balance in radial engines by balancing the sum of all the rotating weights plus one-half the sum of the reciprocating weights.

Our purpose in this paper was to show the wide discrepancies in *pv* factors that were found in practice, not to uphold its use. In fact, many of us at Wright Field do not believe that the *pv* factor is of much use for design purposes. However, it is some kind of a measure of the heat that is generated in a bearing, and, of course, would thus be an indication of how much oil was required to cool the bearing.

Is the 30,000 to 60,000 rubbing factor measured in feet per minute or feet per second?

A MEMBER:—Per minute.

MR. PRESCOTT:—Our values then would be 60 times as great for the same *pv*, because we rate ours in feet per second times pounds per square inch.

SANFORD MOSS[4]:—If we supercharge an engine that is giving good performance to get the high power that was mentioned, will the bearings stand up?

MR. PRESCOTT:—The effect of supercharging is to increase the gas pressure on the power stroke. This force has little effect on the bearings of in-line and V-engines as the V-1570 analysis shows. In the case of a radial engine it is a decided advantage since it reduces the crankpin-bearing load by a substantial amount. The degree of supercharging that is now used has practically no effect on the useful life of the engine bearings.

CHAIRMAN NUTT:—In some engines we must have narrow bearings and we cannot always put the oil into that bearing at the best theoretical point. If we do, the oil will come out of the bearing faster than we put it in, and, therefore, we have a problem of bad lubrication and also over-oiling the cylinders. As a matter of fact, on the Conqueror engine we put the oil into the main bearings at the high-pressure point instead of at the low-pressure point for that very reason. If the bearings have a good enough l/d ratio, then we can get away from such practice.

[4] Thompson Research Laboratory, General Electric Co., West Lynn, Mass.

Modifications of Diesel and Otto Cycles Expected

ONLY ONE EXCUSE exists, apparently, for working on the application of Diesel-cycle engines to aircraft; namely, the reduction in fire hazard.

A cupful of hot oil poured on a red-hot plate will ignite and burn more severely than a cupful of gasoline, nevertheless it is believed that the oil will not explode and throw the fuel in all directions.

To present a picture of the goal which the heavy-oil injection engine must reach, if it is to compete with a gasoline engine, the modern aircraft engine develops its rated power at normal speeds as high as 2450 r.p.m. Fuel consumption as low as 0.39 lb. per b.hp-hr. has been obtained with high-compression engines, in the neighborhood of 7.5 to 8.0:1, with a special fuel. Consumptions between 0.40 and 0.425 lb. per b.hp-hr. may be expected under these conditions from the average production engines with high compression. It may be said immediately that this is a laboratory result and that special fuels are not available to the flier, but at present the Diesel-cycle or heavy-oil injection engine is in the same category in this respect. These low consumptions are obtained with a fuel of an 87 octane rating, which is obtainable by using not over 3 cc. of tetraethyl per gallon of gasoline made from a good California crude.

A few questions about the operation of the auto-ignition engine would be pertinent at this time.

What is the effect of the cold air and low air-pressure at high altitudes?

Is it not possible that the operation of the engine will be seriously affected by these conditions, and will it not be necessary to throw glow plugs into operation at high altitudes or after a long glide without power? This arrangement adds complication and expense, which are claimed by the advocates of this type of engine to have been eliminated.

The cost of such an engine undoubtedly will be more than that of the Otto-cycle engine, since the carbureter is inexpensive as compared with the fuel-injection system.

Many of the comparisons of engine performance appear to be made on a basis of auto-ignition engines which run at slow speed and are very heavy per horsepower. The present liquid-cooled aircraft engine weighs about 1.3 lb. per b.hp. dry, whereas, on account of the high cylinder pressure in the heavy-oil engines, these weights have been considerably exceeded. The lightest heavy-oil engine known in this Country is the Packard aircraft engine, which weighs in excess of 2 lb. per hp. and runs with a brake mean effective pressure of around 100 lb. per sq. in. The modern gasoline engine develops at normal power 140 to 150 lb. per sq. in. b.m.e.p. Brake mean effective pressures of 190 to 200 lb. per sq. in. have been reached in this Country in the laboratory and the English have obtained as high as 225 lb. per sq. in. b.m.e.p. Therefore it can be seen that the possibilities for improvement in the present type of gasoline engine have not been exhausted and that the injection engine is far from reaching even the low limit which is considered marketable in the gasoline engine.

I believe that some modification of the Diesel and Otto cycles will result from all the new studies now under way. Injection of gasoline no doubt will be used in the near future, as it will eliminate many of the inherent difficulties in aircraft carbureters, providing better distribution of the fuel, more power and possibly better economy. Direct injection of this fuel in the cylinder may make possible the use of a lower grade of fuel with a high compression ratio and spark ignition. Elimination of spark ignition is desirable to avoid interference with radio reception, but this can be accomplished by proper shielding.

If the Diesel type of engine can be developed to give the same performance as gasoline engines at the same weight per horsepower, the elimination of the fire hazard will be of considerable advantage. However, if too many compromises in the way of performance and weight are necessary, it seems that it will be wiser to attack the problem from some other angle.—Arthur Nutt, vice-president in charge of engineering, Wright Aeronautical Corp., in discussion at a meeting of the Cleveland Section.

Motor Transport in Military Operations[1]

Transportation Meeting Paper

By Lieut.-Col. Brainerd Taylor, U. S. A.[2]

CONSIDERATION of motor-transport maintenance in military operations requires a general conception of the national military organization for war. This the author outlines, describing the theater of war, its subdivisions, the zone of the interior, communications and combat zones, and the general character—commercial or military—of motor transportation in each zone. The Quartermaster General's responsibility, and the need for centralizing control of motor transport under his direction as provided in the National Defense Act, is indicated.

Maintenance personnel, tool and shop equipment, supplies and various functions are divided into five groups called "echelons," a military term used to designate the groupings of troops, supplies, functions and military command from front to rear of an army. The operation of maintenance in the five echelons is described in detail, the echelons of maintenance being based upon the unit-repair and unit-replacement system in which a physical—and usually a geographical—separation of the function of repair from the function of replacement is emphasized. Hence, the time that vehicles are kept out of productive operation on the one hand and the interference of vehicle operators with shop management and production on the other hand are minimized. The dissipation and waste of spare parts incident to the old system of "vehicle repair and overhaul" are avoided by maintaining a well-balanced reserve of spare unit-assemblies in unit-repair and unit-replacement shops. The unit-repair and unit-replacement system is provided for in motor-vehicle procurement wherein standardization of unit assemblies with maximum interchangeability is considered coincidentally with performance requirements.

In conclusion, the diverging trends in commercial and military motor-transport are indicated and the need for cooperation and coordination in national defense is stressed.

In the discussion, it is stated that the Army's maintenance system is complete, down to the last detail, and that the governing principles should have a very practical interest for the commercial motor-transport operator. Standardization of units and parts is discussed, the scope of maintenance design-possibilities is outlined and Army and civilian operators' problems are contrasted. Simplified design is advocated.

Applying echelon maintenance to commercial fleets is outlined, fourth and fifth-echelon functions are explained, and it is stated that skilled mechanics are not needed in the Army's scheme. The application of motor-vehicles to military use is treated, a parallel is drawn between Army and commercial maintenance plans, the importance of front-wheel drive is emphasized, and means for avoiding confusion while still maintaining motor-vehicles in war are outlined rather specifically.

FOREWORD

THE AUTHOR presented the following paper at the 1930 Transportation Meeting in Pittsburgh, Pa. It sets forth the status of maintenance development in the United States Army motor-transport service as it existed at that time; but, since its presentation, a great deal of progress has been made. The five echelons of maintenance and the practice of unit repair and unit replacement have been advanced. The most striking progress, however, has been made in the actual production of a standardized group of military types of vehicle by the extension of the principle of unit repair and unit replacement to embrace unit design and unit procurement, in accordance with the Quartermaster General's plan of standardization, which contemplates use of standard commercial units exclusively. This plan is based upon the following three cardinal objectives that underlie the entire scheme of military motor-transport development, except in the case of special vehicles procured by supply services other than the Quartermaster Corps which, because of their special features, are not considered a part of the Army's organized motor transportation.

Performance.—The performance requirement, specified for any vehicle by the using service, will be translated by the motor-transport branch, Quartermaster Corps, into specifications covering the performance requirements of each unit assembly to be incorporated in the vehicle.

Quality.—The quality of materials and ruggedness of the vehicle required to meet its military missions through prolonged service and to minimize repair and replacement will be written into each specification covering unit assemblies to be incorporated in the vehicle.

Interchangeability.—The feature of interchangeability will be emphasized as much as is consistent with practical resources in the automotive industry for the Army's war-time requirements, in all motor-vehicle development and procurement, so as to assure the greatest possible economy in motor-transport operations, maintenance and replacements. So far as possible, vehicles will be procured that are interchangeable for different military uses and, where bodies of different design and character are required, the chassis will be procured with a wide interchangeability of chassis in view. Further, where chassis of different sizes and types are required for different uses and different bodies, maximum interchangeability in unit assemblies will be effected by specifying uniform dimensions and attachments regardless of interior design and make.

In accordance with the foregoing cardinal objectives in procuring military motor transport, the Army and the automotive industry have developed in the last year 18 different types and sizes of chassis as indicated in Table 1. This standardized list is based on five sizes of chassis, ranging from $1\frac{1}{4}$ to $7\frac{1}{2}$-ton payload capacity, with four different types of driving combinations in each size except the smallest which, for the present, is limited to two types.

The flexibility of this comparatively small number of chassis to meet an extensively diversified range of military requirements is very great, when diversification in body design to meet operating requirements is considered. The economy in maintenance and in replacing vehicle equipment through replacement of chassis, bodies and unit assemblies is self-evident.

Combined with the unit-repair and unit-replacement system and the five echelons of maintenance, this system of vehicle development and procurement establishes the foundation of a military motor transport for the United States that can, with the continued superiority of its automotive industry, have no equal in the world. Where \$150,000,000 worth of spare parts—or 25 per cent of the cost of the vehicles—failed utterly to maintain over 275,000 vehicles, representing over 200 different makes, in the World War, it is believed that 10 per cent of our vehicle investment expended for extra unit-assemblies and spare parts would be

[1] The paper has special reference to United States Army maintenance of its motor transport.

[2] S.M.S.A.E.—Office of the Quartermaster General, transportation division, motor-transport branch, U. S. Army, City of Washington.

TABLE 1—MOTOR-TRANSPORT STANDARDIZATION CHART

Showing the Plan of Development of Military Motor-Truck Chassis Through Standardization of Unit Assemblies with Interchangeability of Units in Any One Group, To Simplify Automotive Repair and Supply in a Theater of Military Operations. These Allocations Are Tentative. However, If a Heavier or Lighter Chassis Than Is Indicated Is Desired, It Can Be Provided from the Next Higher or Lower Unit Group. It Should Be Emphasized That Interchangeability of Standard Commercial Unit Assemblies Is Contemplated within Each Group.

UNITS

Group-I Chassis			Group-II Chassis			Group-III Chassis			Group-IV Chassis			Group-V Chassis		
Rated Capacity, Tons	Number of Wheels	Drive	Rated Capacity, Tons	Number of Wheels	Drive	Rated Capacity, Tons	Number of Wheels	Drive	Rated Capacity, Tons	Number of Wheels	Drive	Rated Capacity, Tons	Number of Wheels	Drive
1	4	Two-wheel	2	4	Two-wheel	3	4	Two-wheel	5	4	Two-wheel	7½	4	Two-wheel
1¼	4	Four-wheel	2	4	Four-wheel	3	4	Four-wheel	5	4	Four-wheel	7½	4	Four-wheel
..	..	....	2½	6	Four-wheel	4	6	Four-wheel	5 to 6	6	Four-wheel	8	6	Four-wheel
..	..	....	3	6	Six-wheel[a]	5	6	Six-wheel[b]	7½	6	Six-wheel[c]	8 to 10	6	Six-wheel
			[a]Use Group-III Engine			[b]Use Group-IV Engine			[c]Use Group-V Engine					

MILITARY TRUCKS AND BUSES FOR WHICH THE ABOVE CHASSIS ARE SUITABLE

1 to 1¼-ton Cargo Armored Cars Radio Trucks Reconnaissance Cars Wire-Laying Trucks Rations and Baggage Trucks Signal-Corps Trucks Companion Trucks Light Repair Trucks Omnibuses Ambulances Dump Trucks	2 to 3-ton Cargo Repair Trucks Field Generating Trucks Tank Trucks Air-Corps Servicing Trucks Dump Trucks	3 to 5-ton Cargo Tank Trucks Air-Corps Special Trucks Gun Mounts Repair Trucks Photographic Trucks Hot Oil and Water Trucks Mobile Winch Dump Trucks	5 to 7½-ton Cargo Air-Corps Special Trucks Artillery Trucks Wrecking Trucks Barrage Balloon Winch Tank Trucks Machine Shop Water-Purification Trucks Sprinkling Trucks Dump Trucks Tank Carriers	7½ to 10-ton CargoWrecking Trucks Heavy-Duty Refueling Trucks Tank Trucks Coast-Artillery-Corps Heavy-Duty Trucks Dump Trucks

a very liberal estimate under war conditions to accomplish the same purpose for the same number of vehicles, under this system, without serious loss of time in vehicle and shop operations or wastes in automotive-supply inventories. The unnecessary loss of serviceable materials, incident to scrapping disabled and obsolescent vehicles of different makes and models, is avoided in this system. The saving that results from reclamation of unit assemblies that are readily interchangeable with similar units in the fleet represents another very great economical feature. Reduced to a monetary consideration, this system makes practicable a prolonged usefulness of a large part of the original vehicle investment.

If economies of the proportions estimated in the Quartermaster General's plan of standardizing the Army's motor-vehicle equipment are to accrue to its maintenance and replacement costs, to be applied finally to the cost of motor-transport operations, and if these economies more than offset initial increased procurement costs involved so as to reduce the cost of transportation on a ton and a passenger-mile basis, the entire Army system of motor transport merits careful study in connection with commercial transportation. If such standardization can be applied to commercial practice with similar economies, not only would our national defense be improved but our commerce, dependent upon the power and economy of transportation, also would be enhanced in value.

The possibilities in reciprocal development by the Army and by industry of a standardized motor transport in the United States have their precedents in the standardization of railway transportation which, prior to our military experience in the Civil War, lacked the capacity, because of its non-standard character, to permit either military or commercial operations to develop their inherent powers.

TEXT OF THE PAPER

MOTOR transportation in military operations is not a subject of independent organization and operation. It is a part of the problem of transportation throughout the theater of war and must be tied into the organization and operation of transportation throughout the entire theater, to be applied to all military activities as one coordinated national system of transportation. The organization and operation of motor transport as a part of a general transportation system upon which military operations are carried out does not mean that such organization is independent of military organization and operation. It will be found that it is all one system, chiefly commercial at its foundations but military at its points of application to combat and military supply. To understand the organization and functions and the various aspects of motor transport as applied to military operations, it is necessary to outline the organization of a theater of war, the coordinated system of transportation required for the theater of war and the organization of motor transport as a part of that coordinated system, including military establishments and activities.

In prospect of the event that efforts toward the maintenance of peace fail, we must plan war. When or where war may come to us or how extensive it may be, no one can predict. It may be fought in any part of the world; therefore, plans for military operations can and must be made without any threat of hostility to the inhabitants of the land in which we plan to fight. Our plans of war in France bore no hostility to France. Thus we may plan to wage war in Mexico, Canada, South America or China without thought of hostility to the inhabitants of any of these countries. In planning for war-time transportation this wide range of possibilities as to the scene of action is important, inasmuch as each theater of military operations has its own road nets and peculiarities of terrain which will largely determine the means of military transportation

that must be used. Our ideas of roads and mechanical transport, influenced by our experiences in France and the wonderful highway-transportation facilities which we are now constructing in the United States, for commerce and military operations alike, are not altogether safe to rely upon. In France, the ratio of road miles to square miles of territory is about 2 to 1. In the United States it is 1 to 1, with wide variations in different sections of the Country. In Mexico, it is about 1 to 500 sq. miles; in China, 1 to 1700 sq. miles. Due to lack of improved roads and to enemy action making the use of roads difficult if not impossible in the zone of combat, animal transport and multi-wheel drive, mechanical transport is far more important in military operations than the Army at large appears to realize.

Without knowing when, where or how war may come or how extensive it may be, we can organize, for study and planning, a typical theater of war with three subdivisions, in each of which transportation must be treated differently from transportation in either of the other subdivisions because of the radically different conditions that exist in the three zones and the change from civil to military government.

The Theater of War Described

The entire area of the earth's surface involved in war, so far as we are concerned, is called the theater of war. That includes our homeland, our lines of communication or area of supply and the area of combat. The theater of war is subdivided into the zone of the interior and the theater of military operations, which is further subdivided into the communications zone and the combat zone.

The zone of the interior will be the United States proper or that part not included in any theater of operations. In civil war or a war of rebellion, or in war in which the United States were invaded, for instance, it would not include that part of our Country involved in military operations. In the zone of the interior, the general character of transportation will be commercial. It will be commercially owned, operated and controlled, much as it is now in time of peace, or as it was in the World War, under broad Federal administration and in keeping with the general mobilization of the Nation's resources. All military activities—including transportation in the zone of the interior—will, in time of war, as in peace, be administered by the War Department through corps-area commanders. We have nine such areas, each under the command of a major general. Military transportation will be chiefly animal and motor, used in military supply and training. The military use of general transportation will be in the nature of general traffic arrangements made with commercial carriers. The greater part of motor transportation, except the military, in which training is and always must be the principal consideration, will be commercial, and maintained, as in times of peace, by commercial facilities and methods. In times of peace military motor transport could be maintained commercially, but with loss of training advantages too important to surrender.

That country or that part of the world involved in military operations is called the theater of operations. This area will be under the military command of the general especially appointed to command it, as General Pershing was appointed to command the theater of operations and the American expeditionary forces in France. The theater of operations is subdivided into the combat zone and the communications zone. Further subdivision for military administration is not important from a transportation point of view.

The communications zone embraces all lines of communication and supply activities, while the combat zone includes that area necessary to combat operations. The combat zone and the communications zone are commanded by separate commanders, subordinate to the commander of the theater of operations. The commander of the combat zone has as his objective actual combat operations against the enemy. The commander of the communications zone has for his objective the command and administration of supply establishments, evacuation, and lines of communication, thus relieving the commanders of combat of all agencies, burdens and responsibilities, incident to the support and maintenance of the entire forces in the theater, not actually a part of combat operations. In the communications zone the character of transportation is very largely commercial, with much military transport of all kinds operating in conjunction with it. Civilian communities are generally undisturbed and commercial activities continue. Transportation, line and terminal operations, may be foreign, but none the less commercial, and the military transportation imposed upon the commercial system must be coordinated with local commercial and civilian requirements and rights. Military control will necessarily dominate commercial control, but the military commander will cooperate with and rely upon commercial authorities and resources to a very great extent.

In the combat zone, however, conditions will be very different. In this zone, civil life and commerce are greatly disturbed, if indeed they are not paralyzed, destroyed and entirely absent. In this zone transportation is entirely military. It is actually commanded by combat commanders. It is operated and maintained by the military. It is subject to peculiar and everchanging conditions and cannot always be operated and maintained as it is in more peaceful zones and in peacetime commerce.

It is the problem of the operation and maintenance of transportation in the theater of operations, and particularly of motor transport in and for the combat zone, that underlies the scheme of maintenance herein presented.

Motor Transport a Quartermaster Corps Responsibility

Looking further into the future of motor-vehicles provided for the Army, those used in a theater of military operations which may be far removed from our homeland will in most war possibilities be so far removed from sources of commercial automotive repair and supply as to create the most urgent need for conserving skilled repair labor, materials, parts, ship and rail-tonnage in transportation. Therefore, the need for delegating the function of motor-vehicle operation to the military authority charged with motor-vehicle maintenance is evident. It is believed that the need for centralizing all transport functions from procurement to salvage was understood and provided for in Section 9 of the National Defense Act passed by Congress. No surer guide to the quick and successful termination of our next war is believed to exist anywhere than in the provision for coordinated transportation, with centralized military control, so wisely written into this section when the errors of war were fresh in the minds of our law makers.

To some extent, particularly in the case of motor-vehicles classified in general as passenger and cargo-carrying vehicles, all these closely correlated functions, extending through the life of the vehicle from design to salvage and including operation and maintenance, are at present charged to the Quartermaster General. There are, however, many special vehicles and exceptions to the rule, considered military necessities, that keep the subject of maintenance in a very precarious position. The Quartermaster General, who is charged by law with all of the functions of transportation, has among his assistant officers whose experience collectively embraces every phase of military motor transport since its inception on the Mexican Border in

1916, less than five years after motor-trucks began to be manufactured in quantity for commerce. So far as his military authority permits and with well-remembered experiences as the General Staff officer responsible for coordinating and directing the transportation and supply of the First Army, which bore the brunt of our military operations in France, our present Quartermaster General is striving to perfect his organization of transportation in accordance with the National Defense Act before these officers reach the retiring age, so as to provide for efficient operation and adequate maintenance in peace and war. To this end he has published to the Army for its peace-time practice and training for war his plan of motor-vehicle maintenance based upon the system of unit repair and replacement and the conception of five distinct lines of maintenance called echelons[3].

The word *echelon*—defined by Webster as "an arrangement of a body of troops with its divisions drawn up in parallel lines, but each somewhat to the left or right of the one in the rear, like a series of steps"—is a convenient one to use in connection with military formations other than troops. Since our military experience in France, the French form of this word "echelonment" is frequently used in our military terminology. Thus, military supplies and supply establishments and the like are referred to as "echeloned in depth" from front to rear, in which arrangement supplies are stocked in relation to demand, with a few days' supply in advance echelons and 30, 60 or 90 days or more of supplies in rear echelons. Military functions may also be echeloned in depth. This is a particularly convenient conception of automotive-maintenance functions which coincides with the practical echelonment in depth of automotive supplies. The combined and balanced echelonment of automotive repair and supply in depth is the only logical arrangement of maintenance in the military service in which both functions and supplies can be made to coincide with the echelons of military command, wherein the commanders of military units are invariably arranged in depth, or from front to rear in a theater of operations, in accordance with increasing rank and authority in the military chain of command; that is, the regiment, brigade, division, corps, army and group of armies.

The Echelonment of Maintenance

The following is quoted from 1930 Circular 1-10, Office of the Quartermaster General:

> The organization of automotive maintenance will be echeloned in depth. The echelonment of supplies will extend from spare parts carried on motor-vehicles to the centralized stockage in motor-transport depots similar to the echelonment of general supplies. The echelonment of maintenance functions will extend from the work of the driver to the major operations of reconstruction shops, similar to the echelonment of surgical operations from first-aid dressings back through field and base-hospital operations.
>
> In large military organizations, both territorial and mobile, the work of automotive repair and handling of automotive supplies will be so graded in the echelons of maintenance as to remove all repair facilities, that is, shop and warehouse operations, unless highly mobile in character, from the field of motor-vehicle and train operations. In corps areas and departments, as in a theater of operations in war, the more difficult repairs, heavy machinery and heavy stocks of supplies, which are inconsistent with the principle of mobility, will be located at varying distances from the front lines of motor-vehicle operations carried on in connection with the training of troops, and in post, camp and station transportation. Such distances are theoretically in direct ratio to the degree of immobility represented by shop operations and the mass of automotive supplies involved. The most extensive repair operations, requiring skilled mechanics, always limited in number, the heavy immobile shop equipment and the great mass of automotive supplies, will be centralized in motor-transport depots under the control of the Quartermaster General, except for such decentralization of repair personnel, machinery and supplies required to operate fourth-echelon repair-shops as may be found practicable to establish in corps areas with funds allotted the Quartermaster General for maintenance of motor-vehicles.

[3] See 1930 Circular 1-10, office of the Quartermaster General, City of Washington.

The Five Echelons of Maintenance

There are five natural echelons of maintenance, as shown in Table 2, in each of which there are three distinctly different elements; namely, the personnel, the shop and tool equipment, and automotive supplies. The organization of maintenance echelons will be assigned to appropriate echelons of command in accordance with their distinctive characteristics of varying mobility and mass. Throughout the five echelons, the three elements—personnel, equipment and supplies—will be graded in accordance with the character of maintenance to be performed, and within the limit of funds appropriated for pay of personnel, for shop maintenance and for purchase of automotive supplies.

The functions and responsibilities in each of the five echelons of maintenance will be as follows:

First Echelon; Vehicle-Drivers' Maintenance.—This will include cleaning, lubricating, servicing, and tightening of bolts and screws; in short, that daily attention which keeps a vehicle in perfect mechanical order and, in appearance, up to military standards for well-kept equipment. It will include also emergency roadside repairs such as are required of and can be accomplished by the driver, aided by his tool-kit and the spares usually carried on the vehicle, so that it can be continued on its mission or returned to its organization. This is the same kind of maintenance that is required of every soldier to whom a rifle is issued.

Second Echelon; Fleet Operators' Maintenance.—This will embrace periodic and systematic inspection by an officer and his assistants to assure thorough and constant vehicle and fleet maintenance with enforcement and correction of the work of the first echelon. The first and second echelons together will form "preventive maintenance" for which the officer in immediate command of the fleet is directly responsible. The repairs undertaken will be limited to those which can be accomplished by company personnel with the assistance of the company mechanic and his tools, and the company's stock of spares as prescribed by War Department publications. All post, camp and station commanders and commanding officers of military organizations having motor-transport equipment, are responsible for first and for second-echelon maintenance. This is the same kind of maintenance required of every company and post commander connected with Saturday morning and monthly inspections, and is absolutely necessary for the upkeep of all military personnel and equipment.

Third Echelon; Unit Replacement.—This contemplates a removal of an unserviceable unit-assembly in which a subassembly or part needs a repair and immediate replacement thereof by a similar serviceable unit-assembly held in third-echelon stock or to be obtained from fourth or fifth-echelon stocks of spare units at the rear of the army. Unit replacement will be practised in all cases unless it is unmistakably obvious that a minor repair or replacement of a subunit assembly or part is all that is required and that this repair or replacement can be made without removal of the unit assembly from the vehicle or without dismantling the unit, and that the supplies required are on hand or quickly and readily obtainable.

Third-echelon maintenance further contemplates or-

TABLE 2—MOTOR-TRANSPORT MAINTENANCE IN THE FIVE ECHELONS

The Organization of Maintenance Is To Apply To All Wheeled Motor-Vehicles in All Three Groups of Motor-Vehicle Operations Indicated Below

Administrative Organization.—Will Embrace Operation and Maintenance	Group I — Motor-Transport Units, Quartermaster Corps Mission: Transportation and General Supply Units — Motor-Transport Companies and Quartermaster's Trains, Post, Camp and Station Motor-Transport Pools and Centers	Group II—All Other Units of Combat Arms and Supply Services Operating Motor-Vehicles Mission: Tactical Supply Units—Battalions or Regiments of Combat Arms; Units of Auxiliary Services; Motorized or Partly Motorized, Operating Wheeled Motor-Vehicles	Group III — Units of Mechanized Forces Operating Motor-Vehicles Mission: Combat Units—**Proposed Only.**—Vehicles Will Be Both Tracklaying and the Latest Developments in Wheeled Vehicles for Cross-Country Operation. Wheeled Types Will Be Included in This Organization of Maintenance
Operating Organization.—Will Include the First Two Echelons	Number of Wheeled Vehicles: In War.—Set Forth in Published Tables of Organization, Being Approximately 6000 for Each Field Army In Peace.—Authorized Allowance Published in War-Department Circulars	Number of Wheeled Vehicles: In War.—Set Forth in Published Tables of Organization, Being Approximately 19,000 for Each Field Army In Peace.—Authorized Allowances Published in War-Department Circulars	
Maintenance Organization.—Will Embrace All Operating Units and Motor-Vehicle Equipment			
First Echelon Vehicle-Drivers' Maintenance Preventive Maintenance Responsibility of Each Driver	Essential Elements: Personnel.—Drivers and Assistant Drivers Prescribed Functions: Regular Cleaning and Lubrication Servicing.—Air, Oil, Water, and Tightening of Bolts and Screws, Emergency Road Repair	Equipment.—Vehicle Tool-Kits	Supplies.—Spares Usually Carried on Vehicles
Second Echelon Fleet-Operators' Maintenance Preventive Maintenance Responsibility of the Immediate Commander	Essential Elements: Personnel.—Drivers and Company Mechanics under Direct Supervision of a Commissioned Officer Prescribed Functions: Regular Inspection, Correction of Errors or Neglect in First-Echelon Work, and Assistance to Vehicles Broken Down on the Road	Equipment.—Vehicle Tool-Kits, Improvised Garage Facilities, Greasing Pit and Wash Racks, and Emergency-Repair Trucks	Supplies.—Spares Usually Carried on Vehicles and a Small Stock of Extras, Not More Than 20 Items for Each Make of Vehicle
Third Echelon Unit-Replacement Maintenance Responsibility of the Commanding General and Commanding Officers of Selected Posts, Camps, and Stations as Designated by Higher Authority	Essential Elements: Personnel.—Small Maintenance Organization of General Mechanics under an Officer Qualified in Motor-Vehicle Mechanics Prescribed Functions: Removal and Replacement of Unit Assemblies, and Exchange Normally with Fourth-Echelon Unit-Repair Shops. Exchange with Fifth-Echelon Shops When Authorized	Equipment.—Mobile Shop, or Improvised Shelter, with Hand Tools Required for Removing and Replacing Unit Assemblies	Supplies.—Spare Unit-Assemblies and Spare Parts Most Frequently Needed, the Installation of Which Does Not Involve Dismantling Unit-Assemblies. Not More Than 100 for Each Make of Vehicle
Fourth Echelon Unit-Repair Maintenance Responsibility of Corps Area, Department, and General Headquarters Commanders	Essential Elements: Personnel.—Large Maintenance Organization of Various Trade Classifications in the Automotive Industry Prescribed Functions: Repair of Unserviceable Unit-Assemblies in Shop Programs, Based on "Quantity-Production Methods" and a Quick Return of Repaired Unit-Assemblies to Reserve Stock for Third-Echelon Use	Equipment.—Stationary Shops, and Light Tools and Machinery Required by the Various Trades	Supplies.—Spare Unit-Assemblies and a Limited Stock of Spare Parts Required for Their Repair. Not More Than 500 to 1000 Items for Each Make of Vehicle
Fifth Echelon Unit-Reconstruction Maintenance Responsibility of the Quartermaster General and the General Headquarters Commanders	Essential Elements: Personnel.—Extensive Manufacturing and Automotive Supply Organizations of All Trade Classifications in the Automotive Industry Prescribed Functions: Reclamation of Units and Parts; Salvage and Manufacture of Vehicles, Units and Parts; Extensive Warehousing, Storage, and Issue	Equipment. — Extensive Stationary Plants Composed of All Shops and All Machinery, Tools and Facilities Pertaining to the Automotive Industry	Supplies.—All Spare Unit-Assemblies and Spare Parts. A Stock of Machinery, Tools, and Accessories Required To Maintain Motor-Vehicles. From 2500 to 3500 Items for Each Make of Vehicle, Irrespective of Accessories, Tools, and Machinery. Raw Materials as Required

ganization of unit-replacement shops in all large pools of motor vehicles, or at replacement centers established in corps areas and departments relative to a number of small fleets operating at comparatively nearby posts, camps and stations. It positively does not contemplate practise of unit replacement in small military units or at posts, camps and stations at which are located small motor-transport fleets not authorized to operate in the third echelon of maintenance. Before undertaking or authorizing operation in the third echelon of maintenance at any post, camp or station or within any military organization, a corps area or department commander will assure himself of the existence of all three elements of third-echelon maintenance.

In undertaking or authorizing third-echelon work where such work is not contemplated in the regular set-up, a commander will consider the following:

(1) The mechanical personnel must be capable of performing the contemplated work without damage to vehicle or assemblies.

(2) The shop and tool equipment required for third-

echelon work must be on hand at the location where the work is to be done.

(3) The spare unit-assemblies, spare subassemblies or spare parts required in the work contemplated must be in immediate stock at the place where the work is to be done, or easily and quickly obtainable by shipment from the next higher echelon of automotive supply or from some other third-echelon stock in the vicinity. This availability must be established as certain before removal of an unserviceable unit-assembly from a vehicle for the purpose of replacement is justified.

Unless the foregoing three requirements can be fulfilled, the vehicle should be sent to the nearest established third-echelon shop.

Fourth Echelon; Unit Repair.—This will embrace the "tear down" and repair of any or all unit assemblies which are used in the motor-vehicles of the command to which the fourth-echelon unit-repair shop is assigned. Fourth-echelon work contemplates a balanced personnel organization composed of the various types of mechanics, classified and qualified in accordance with the various trades; that is, electricians, welders, engine repairers, carpenters, painters, upholsterers and others required to repair the various unit-assemblies of the motor-vehicles involved. It contemplates the organization, operation and maintenance of shops of the various types used in the trades referred to, and also the extensive supply of spare unit-assemblies, subassemblies and spare parts required in unit-repair operations. In all fourth-echelon shops the three essential elements—trade-classified personnel, the shop and tool equipment and the required supplies—must be in balance in accordance with minimum requirements established by the Quartermaster General.

Fourth-echelon unit-repair shops will be organized, maintained and operated under the jurisdiction of corps-area commanders. These shops ordinarily will be operated by motor-vehicle-repair organizations of the Quartermaster Corps in accordance with the unit-repair and unit-replacement system. As a rule, these shops will be concerned only with the repair of unit assemblies and subassemblies. When the repair of a vehicle or vehicles is imposed upon the fourth-echelon shop, it will remove and replace unserviceable unit-assemblies in accordance with third-echelon principles and practice, absorbing the unit-repair work in its normal operations. However, there should always be physical separation between third and fourth-echelon operations because of the distinctly different objectives involved. The objective of a third-echelon shop is to return vehicles to service in a serviceable condition as quickly as possible. The objective of a fourth-echelon shop is good shop organization, a smoothly running program with work of first-class quality and a high rate of production in view, measured in terms of the number of unit assemblies repaired and returned to stock each month.

Fourth-echelon shops will reclaim all serviceable unit-assemblies, subassemblies and spare parts from motor-vehicles and motor-transport equipment authorized by the Quartermaster General for reclamation. In the operation of fourth-echelon shops the work of repair of unit assemblies and subassemblies will be balanced with corps-area requirements on the one hand and the capacity of fourth-echelon shops to turn out such required repairs on the other hand. In this connection, fourth-echelon shops should evacuate work beyond their capacity to fifth-echelon shops to which they may be assigned for supply.

Fifth Echelon; Reconstruction.—In addition to repair and manufacture, this will embrace the reclamation and salvage of motor-vehicles, unit assemblies and subassemblies to replenish stocks from uneconomically repairable vehicles which, nevertheless, constitute a source of free supply of serviceable or economically repairable unit assemblies, subassemblies and parts. It also includes assembling of units, subunits and vehicles. Whereas a large percentage of supplies of the fourth echelon is in spare unit-assemblies and subassemblies, the supplies of the fifth echelon must embrace every indivisible part of such assemblies and subassemblies and the raw materials; that is, steel, copper, alloys, wood, cloth, leather, wire, acid, paints, and other materials essential to automotive remanufacture.

The fifth echelon requires the organization, operation and maintenance of extensive establishments composed of various trade shops and the warehouses that are absolutely immobile and similar in character to manufacturing establishments in commerce, where motor-vehicles, unit assemblies and accessories are originally fabricated. This echelon of maintenance is the special responsibility of the Quartermaster General, under the direction of the Secretary of War. It will be performed, at specially organized depots, as directed by the Quartermaster General.

Fifth-echelon shops will cooperate in every way with fourth and third-echelon shops assigned to them for supply so as to accomplish, between the three echelons, the work of unit repair and unit replacement. Fifth-echelon shops will endeavor to maintain a smooth flow of supplies and reserve stocks through both the fourth and third echelons. Whenever fourth and third-echelon work is imposed upon fifth-echelon shops, such work will be performed in accordance with the principles and practices of third and fourth-echelon shops. A physical separation, however, between third-echelon work of unit replacement and the higher echelons of unit repair and unit reconstruction should always be maintained, to protect fourth and fifth-echelon shops against the loss of man-labor hours that always attends the repair of specific motor-vehicles. Assignment of special priorities, being inconsistent with the organization and operation of shop programs, will be avoided as much as possible in fourth and fifth-echelon shops. This will be accomplished by assigning priorities to third-echelon shops and keeping such shops stocked with spare units with which to turn out quick repairs and overhauls in response to the orders establishing priorities.

The echelonment of maintenance functions described herein is in no sense different in principle from the echelons of maintenance existing in commercial practice. Each owner or driver of a motor-vehicle practises first-echelon maintenance, more or less. Every owner or manager of a small fleet of vehicles must practise second-echelon maintenance much as it is described for Army practice, else his costs of operation and maintenance will become a serious matter. The third echelon is practised by large-scale fleet operators. It also is represented by small local public repair-shops and dealers which carry limited stocks of spare parts. The fourth echelon is also practised by large-scale fleet-operators and is represented by the larger more centrally located shops and dealers and the manufacturers of unit assemblies. The fifth echelon is represented by the motor-vehicle factories where vehicles, units and parts are originally fabricated. This echelon in commerce is also used by the Army in its peace-time maintenance.

Many large-scale fleet-operators in commerce practise all five echelons of maintenance along the same lines as those of the Army. Intermediate-scale fleet-operators operate the first two or three and some of the functions of the fourth and fifth echelons, or they may find it more economical to let contracts for all fourth and fifth-echelon work. The five echelons are practised just about the same in commerce as in the Army, but not under one authority or control, as a rule; therefore,

the lines of demarkation and separation of functions cannot be so clearly defined as they have to be in military practice.

The Three Elements of Maintenance

The Quartermaster General's regulations continue as follows:

The three essential elements of maintenance, that is, personnel, shop and tool equipment, and supplies, will be graded throughout the five echelons in accordance with the requirements of operating vehicles and fleets on the one hand and, on the other hand, the necessity for maintenance organization, which requires the economical distribution of funds and the centralization of limited elements. The highly trained personnel required for the fourth and fifth-echelon work is always very limited. The shop and tool equipment used by such personnel is likewise limited. The third element, automotive supplies, never adequate even in war for decentralization to posts, camps and stations, must be kept under the control of the Quartermaster General in fifth and fourth-echelon shops. In the use and distribution of these three elements, incident to setting up the five echelons of maintenance, the following resources are available in the Army:

The Personnel Element

(1) The first echelon will include enlisted men of all arms and services who are or can become qualified to drive and care for motor-vehicles.

(2) The second echelon will include officers, non-commissioned officers of all arms and services, and specially selected enlisted men trained and qualified to operate and maintain small fleets of motor-vehicles.

(3) The third echelon will include trained mechanics and officer personnel with general automotive mechanical knowledge and experience. This echelon will include all technical organizations, composed of such mechanics as quartermaster motor-repair sections and ordnance-repair companies, and such improvised units composed of enlisted men having general mechanical knowledge as can be organized by corps-area and department commanders and trained to operate efficiently in the third echelon of maintenance. This personnel will function under the control of the commanders to which assigned, as directed by corps-area and department commanders in establishing unit-replacement centers.

(4) The fourth echelon will be limited to regular quartermaster organizations augmented by details of similar technical organizations belonging to other services and by detail of specialized mechanics, qualified in one or more of the trades connected with the automotive industry, and by officer personnel trained in automotive mechanics and maintenance management. These organizations, however, to function properly in fourth-echelon work, will be balanced as to trade qualifications in accordance with well-established automotive shop-organization and practice. This personnel will function under the direct control of corps-area commanders.

(5) The fifth echelon will be limited entirely to quartermaster motor-repair companies and battalions which may be augmented by the detail of highly skilled personnel qualified to reconstruct and manufacture vehicles, unit assemblies, subassemblies and parts, or by personnel to be trained during such detail. This personnel will be under the direct control of the Quartermaster General.

The Shop-and-Tool-Equipment Element

(1) and (2) The first and second echelons will be limited to small kits of hand tools which come originally with every vehicle upon its leaving the factory, augmented in the second echelon by mechanics' tool-kits and such extras as may be carried on the company repair-truck. Greasing pits, wash racks, and similar service facilities permanent or improvised belong to the second echelon.

(3) The third echelon will be limited to such hand tools as are required to remove and replace unit assemblies, and to such simple repair equipment as may be carried on a mobile machine-shop truck, which is required for minor repairs incident to field operation. In addition, the third echelon, when set up as a semi-immobile shop, may have added work benches, vises, air compressor, paint-spray machine, high-pressure lubricating devices, heavy-type vehicle-jacks, and a limited addition of small hand tools, such as tap and die sets, carpenters' tool-kits and the like, as specified by the Quartermaster General.

(4) The fourth echelon will include the machinery and equipment required in shops of the various trades connected with the automotive industry required to repair unit assemblies.

(5) The fifth echelon will include similar but more extensive equipment required for the reconstruction and re-manufacture of vehicles, units and parts.

The Automotive-Supplies Element

(1) and (2) The first and second-echelon supplies will be limited to the few spare parts intended to be carried on vehicles and spare vehicles of companies of small fleets.

(3) The third-echelon supplies will consist of a reasonable proportion of a reserve stock of spare unit-assemblies and subassemblies, and of a small stock of frequently required spare parts that do not require the dismantling of unit-assemblies to install, as authorized from time to time in circulars issued by the Quartermaster General. Supplies of the third echelon will be located within corps areas and departments by corps-area and department commanders; decentralization of such supplies from corps-area fourth-echelon-supply stocks to be made at their discretion.

(4) The fourth-echelon supplies will include reserve stocks of spare unit-assemblies and subassemblies and such stocks of spare parts required to repair unit-assemblies and subassemblies. The character and quantities of such supplies will be authorized from time to time in circulars published by the Quartermaster General in accordance with available stocks and funds appropriated for maintenance of motor-vehicles.

(5) The fifth-echelon supply will consist of centralized stocks of automotive supplies, including raw materials, to be held under the control of the Quartermaster General.

The maintenance of motor transporation, including the general set-up of the five echelons, the establishment of maintenance systems and policies, is the responsibility of the Quartermaster General under the direction of the Secretary of War. The operation of maintenance echelons assigned to any command, together with all maintenance of vehicles contemplated as the functions of such echelons, will be responsibilities of commanding officers.

Fifth-echelon maintenance will be limited to Quartermaster Depots at Camp Normoyle, San Antonio, Tex.; Camp Holabird, Baltimore, Md.; the Jeffersonville Depot, Indiana; and the General Depot in San Francisco, Calif. Responsibility will rest with commanding officers of these depots under the direction of the Quartermaster General.

This distribution of the large automotive supply depots and shops contemplates taking care of all fifth-echelon work for the central southern, eastern, central

northern and western portions of the United States in time of peace. In this distribution of fifth-echelon depots under the Quartermaster General's control, the assignment of lower echelon shops with regard to automotive supply is made with consideration of rail and water-transportation connections. In the event of war the motor-repair battalions that operate these four fifth-echelon depots would form the fifth-echelon repair-units to be sent initially into a theater of operations, their work in the home depots being taken over and continued if in the zone of the interior by civilian mechanics and new military units organized and trained thereat for service in the theater of operations.

The Unit-Repair and Unit-Replacement System

The unit-repair and unit-replacement system contemplates the development of 18 to 20 different sizes or models and 4 different types of motor-truck chassis for all military purposes from five basic models of the four-wheel-drive type as shown in Table 1, the special needs of the Army to be met with special bodies as shown in the lower portion of the Table.

Reasons for Unit Repair and Unit Replacement

The background of experience which supports the Army's opinion that unit repair and unit replacement constitute the only possible system that can be practised in military motor transportation, and the changes that have taken place in military motor transportation that point toward the necessity for extending this system to include unit-assembly procurement and development to produce standardization and interchangeability of units are outlined briefly as follows:

(1) First, the mechanical unit in motor transport in 1917-1918 was the motor-vehicle; designed, developed and produced as a complete article of standard commercial manufacture sold under a trade name.

Second, except in the case of passenger vehicles and motorcycles, which form a relatively small percentage of the Army's motor-transport equipment, the mechanical unit in motor transport today is the unit assembly; designed, developed and produced as a complete article of standard commercial manufacture and sold generally to any manufacturer or assembler of motor-vehicles. Such units are, therefore, available as replacements procurable in quantity by the Army.

(2) First, the number of parts involved in maintaining motor-vehicles in 1917-1918 constituted an impossible problem in supply, so far as the theater of military operations was concerned. It was most unsatisfactory even in the United States, our zone of the interior. This situation is shown in the records of Congressional investigation held in 1919-1920. Had the war continued six months longer, a serious breakdown of field transportation in the entire Army could not have been avoided. Of the 500,000 different items of spare parts involved and required, not over 20 per cent ever reached France and those were most unbalanced, ranging from absolutely no replacements of vitally essential parts to mountains of spare parts in advance depots, as well as depots all along the line, that never would have been needed in 10 years of war.

Second, stocks of spare unit-assemblies, subassemblies and the most frequently needed spare parts required for the maintenance of such units, if interchangeability of units is provided for in design, constitute a comparatively simple automotive-supply problem that lends itself to military operations. It is just as easy to transport, store and issue boxes and crates containing unit-assemblies throughout the entire theater of war as it is to handle boxes and crates containing spare parts, and in the zone of combat it is impossible to handle spare parts in required quantities. The actual handling of units in shops and warehouses is infinitely quicker and easier than handling the same when broken down into separate parts. The unnecessary transportation and stockage of parts assembled in units that do not need frequent replacement incident to the unit-repair and unit-replacement system is more than offset by the simplicity of repair in the zone of combat and other advantages of the system.

(3) First, the necessity for standardization within a minimum number of motor-vehicle trade names was an outstanding conclusion of the World War.

Second, standardization of motor-vehicle equipment needs no defense, even in commerce. In war, it is a vital military necessity. Standardization of vehicles by trade names is impracticable because of the limitations of manufacture by any small group. It is also undesirable in the Army. The law forbids it in time of peace, and the great number of variations and modifications in motor-vehicle equipment required to meet the special needs and missions of the different Arms and Services will not permit it in our next war. Through standardization of unit-assemblies and subassemblies, however, with interchangeability of like units in vehicles of the same general types and class, vast economies in maintenance and advantages in operations, essential to continuance of automotive power in military operations, are possible.

For example, axles, variously designed by several different manufacturers, necessitating the use of different parts that are not interchangeable because of the play of originality in design, may be suitable for military operations; and several axles now manufactured will meet Army specifications. If Army or S.A.E. Specifications establish standardized outside dimensions and characteristics with regard to the installation of such axles in trucks manufactured or assembled by different concerns, the standardization with interchangeability required by the Army can be established on a practical basis, and the maintenance of axles in the theater of operations will present a problem that can be solved if not too many designs are involved.

In accordance with the echelonment of maintenance and the unit-repair and unit-replacement system, stocks of spare parts required to repair the axles can be centrally located in fourth-echelon shops where shop programs contemplate repair of a number of axles of similar design at one time. In the many third-echelon shops required to be near the operating vehicles the repair of trucks, so far as axles are concerned, can be made quickly by pulling out the unserviceable axle and replacing it in short order with a similar axle even if of different make. Daily trains move from regulating stations in the railway system well at the rear of combat, through which all depot supplies move up to fighting divisions and all other troops in the combat zone. Axles can be shipped up with other supplies on the daily trains as required, and unserviceable axles evacuated by the returning trains to the fourth-echelon unit-repair shops.

Every other unit-assembly in truck equipment can and should be handled in the foregoing way. Only through standardization of units and the systems of unit repair and unit replacement can we avoid dissipation of required and limited stocks of spare parts. Through practice of the unit-repair and unit-replace-

ment systems we may prevent hoarding in small organizations of spare parts which heretofore operating personnel have considered necessary to keep their vehicles running. Other organizations sorely needing every truck in their outfit to meet some military emergency that may be infinitely more important than any facing the organization guilty of hoarding cannot be served if central stocks are dissipated and hoarded. Further, the stocking of spare parts in many points where maintenance work is done, instead of unit-assemblies, is extravagant beyond conception; it also sets up immobility and confusion in fleet operations that constantly and rapidly grow worse.

The supply of spare parts to troops for the purpose of their making their own repairs has been exhaustively tried out, and it is hopeless to expect it to work satisfactorily.

By a physical separation of unit-replacement shops from unit-repair shops, priority orders involving 100 per cent of overhauls can be attended to in replacement shops without material interference with the shop programs of unit-repair shops. The loss of man-labor hours and production in the larger fourth and fifth-echelon shops can be materially reduced. With the physical separation of replacement and repair, there must be adequate stocks of reserve unit-assemblies provided to meet the requirements of unit-replacement shops. In such a system there is no need for permitting priority orders pertaining to a vehicle to extend beyond the third echelon; that is, into unit-repair shops where production is the objective.

Conclusion

In conclusion, attention is called to the diverging requirements of commerce and war regarding the use of highways that need forethought and coordination in time of peace. These will materially affect maintenance in the Army.

In commerce, we are engaged in a most extensive roadbuilding program that represents an engineering and financial operation exceeding that of the building of the Panama Canal, until now standing as a great monument to American enterprise. These roads are expanding the uses of comparatively inexpensive, simple, two-wheel-drive vehicles, manufactured on a commercially competitive basis where price variations of small amounts or differences in design of various parts of the vehicle have important sales results.

In war, we contemplate the use of this great system of roads, at least in our zone of the interior. Here, the commercial vehicle as produced will serve our military requirements, except for military training. In the theater of operations, however, whether or not an equally extensive, improved highway network exists, military motor transport cannot count upon good roads. Modern war with its extensive and accurate artillery fire, destructive gases, and overwhelming aerial operations will deny the use of roads to a much greater extent than ever before. Not even night operation of transport will, it is believed, be possible in forward areas to the extent to which such operations were developed in the World War. The long columns of slowly moving trucks that nightly moved up to supply the Allied and German Armies surely will be easy targets for airmen armed with modern means of illumination and destruction. Widely dispersed, small groups of cross-country supply-columns moving up in the rear of combat operations in which powerful cross-country motor-vehicles play an important rôle are clearly seen as modern field transportation in war.

The Army's conception of this type of required motor transport is to be seen in the powerful multi-wheel-drive vehicles recently developed in Army field-tests and procured in accordance with the Army's specifications describing the various unit-assemblies required to produce an all-round cross-country truck suitable for many military purposes. In the production of such vehicles, conceived as an assembly of interchangeable mechanical units of standard commercial manufacture, available to any manufacturer who is interested in meeting the Army's requirements, can the coordination of commercial and military development be expected. Unless general understanding of the problems outlined in this paper can be made to exist, and cooperation effected between all concerned with the Army's motor transport, we shall find ourselves, even with our unparalleled position as the world's foremost motor-vehicle-producing nation, at great disadvantage in military operations against an enemy that is so farsighted in this matter as to practise subsidization to both purchasers and manufacturers of motor-vehicles to produce suitable military motor transport. Such is the case to some extent in at least two countries, England and Japan.

So important to successful military operations has the motor-vehicle become, and so vulnerable are improved roads and long trains of vehicles to modern methods of warfare, that there should be no hesitancy in separately classifying military and commercial types of motor-vehicles, although in most characteristics their requirements, except for cross-country ability, are essentially the same. Although commercial vehicles can and will be used in great numbers by our military forces during war, as produced for commercial purposes, the military vehicle upon which we must rely for success in the zone of combat must possess high road-speed with a high degree of cross-country ability and, withal, great sturdiness throughout and simplicity in operation and maintenance. This will involve:

(1) Powerful and adequately cooled engines mounted on multi-wheel-drive chassis, driving on at least two axles, *one of which must be the front axle*

(2) The use of large dual balloon tires giving maximum flotation on sandy and soft muddy surfaces

(3) A high range of gear ratios with six or seven speeds forward and at least two in reverse in our largest vehicles

(4) The best quality of materials used in unit construction to give as much sturdiness and maintenance simplicity as possible

(5) Last, but not least, standardization of unit-assemblies and subassemblies and, as far as possible, in parts, with a high percentage of interchangeability between unit-assemblies, subassemblies and, to some extent, in parts, in vehicles of similar tonnage classification, in view of maintenance requirements in a theater of operations

In a country where subsidization is not practised in military preparedness for national defense, voluntary thought and action on the part of the producers and users of motor-vehicles are necessary. If it is not practicable to produce motor-vehicles for commercial purposes that can be qualified as military vehicles according to the foregoing outline, because of the increased cost of such vehicles, it is possible in producing unit-assemblies, subassemblies and parts to qualify with military specifications. Such supplies will be available to any and all manufacturers for purchase and incorporation into vehicles of their own manufacture, produced for commercial use, to build such vehicles up as indicated in the Army's standardization chart, for sale to the Army or to any other branch of the Government, or to any user who desires a vehicle or parts of a vehicle that comply with Army standards.

These are the high lights in military motor-vehicles required for field transportation in the theater of oper-

ations of our next war, should we unfortunately become involved in one. Whereas it is a fact that no nation can afford to build purely military transportation, field transportation used in the combat zone is too vital to national security to be ignored in time of peace. Its development, operation and maintenance, are prime considerations affecting the safety of our Nation and its every citizen.

THE DISCUSSION

COL. F. H. POPE[4]:—The able and thorough discussion of the system of Army motor-transport maintenance, presented by Colonel Taylor, expresses the mature views of those Army officers who have been intimately associated with military motor-transport since it first became a factor in our military service almost 15 years ago. This subject should be of especial concern at present to the automotive industry, for reasons of self-interest as well as for those that are sometimes erroneously believed to be of a disinterested or academic nature.

The Army is now giving special attention to the subject of mechanization, or the use of mechanized vehicles in combat. An experimental mechanized force has been organized that will be equipped with all the latest and most modern motor-transport equipment that the Army has on hand. This development, coupled with the fact that practically all the war-time-vehicle equipment of the Army will soon disappear from the scene, indicates that the Army may be in the market for modern motor-transport equipment in the not distant future. This is the primary reason of self-interest that should attract the attention of industry to the military requirements for motor transport set forth by Colonel Taylor.

Another practical reason for self-interest arises from the fact that the Army is and for years has been one of the largest single operators of motor transport in this Country. Probably no organization in this hemisphere, under a largely centralized control, supervises a motor-transport organization of more varied operating conditions, both as to terrain and personnel, and a more complete maintenance or service system down to the last detail, than does the Army, with its activities throughout the continental limits of the United States and its foreign possessions. Therefore, the principles governing such operation, based on experience of such varied nature and of such duration, should have a very practical interest for the commercial motor-transport man. The other reasons, generally considered of an academic nature, pertain to the subject of national defense, which is a matter of interest that should be by no means confined to the Army.

Many years ago, one of our great military thinkers said, "Armies do not make wars, but wars make Armies." Or, in the modern version of this military axiom, it is not the civilian element that assists the military in time of national emergency, but it is the military that assists the civilian in restoring the peace that the civilian element itself has lost. Certainly, commerce and industry have much more to lose in a war than has any professional military man. Therefore, it appears clearly evident that this discussion of motor-transport maintenance from the military viewpoint should be of active interest to the automotive industry.

Commercial and Military Requirements Vary

Colonel Taylor's exposition of the general organization of the military transportation system in a theater of war is clearly set forth, and needs no comment; but I desire to emphasize one or two points, about which there may seem to be a variance between commercial and military requirements. First, all industrial organizations are designed to produce an article that can be sold for profit. The production of a dividend is, in the last analysis, the basic principle in all industry and commerce. Therefore, in design and in quality of material, the construction of a commercial vehicle is in a very large degree controlled by the exigencies of a highly competitive market. Motor-vehicles must be built to a price, and not to the ideal of an automotive designer. The sales department generally controls the engineering or design department. On the other hand, the exigencies of military operations preclude this condition. Certainty of action is one of the prime essentials for military success. In military life, all other considerations must give way to certainty of action; therefore, a military vehicle must be built up to a standard and not down to a price. This may be rather crudely stated, but it is not believed that this general statement can be controverted.

In addition to certainty of action, a military organization must be very flexible to meet a wide variety of conditions which cannot be anticipated and about which advance information will rarely be available. These two principles require military vehicles to be of rugged character and standardized design, and capable of affording the greatest interchangeability, not only for operating activities but for maintenance requirements. This is especially the case in a theater of operations where the Army must rely upon its own service and stock facilities, and can never expect the specific territory to be dotted with commercial-service facilities in an efficient operating condition.

"Echelonment" a Suitable Term

There is nothing to add to the description of the echelons of maintenance or to the elements of maintenance as set forth by Colonel Taylor. Some automotive men may be inclined to balk at the term "echelonment," but this is a very common term in military parlance and is, in fact, very much less abstruse than the verbiage of many high-powered automobile salesmen. The remarks as to the desirability and efficiency of the unit-repair and unit-replacement system are concurred in thoroughly, and it is firmly believed that the reasons therefore cannot be disproved.

Standardization of Units and Parts

But the essential principle underlying the requirements of military motor-transport equipment is the absolute necessity for standardization of units and parts. This brings to mind an experience of about 14 years ago. In the late summer of 1916, during a practice march of a provisional division composed in great part of National Guard troops in Federal service, the column was joined for several days by Roy Chapin and Howard Coffin, who were very much interested in the work of the motor-transport elements, of which there were about seven motor-transport companies from Fort Sam Houston. Many conversations took place at that time relative to standardization; but, in those days, it seemed to be a question simply of standardizing in the more or less minor elements such as nuts, screws and bolts, or what the military maintenance man calls "parts common."

Standardization has made great strides in the automotive industry since that time and, along military lines, it is desired to see it go much farther. Standard-

[4] S.M.S.A.E.—Office of the Quartermaster General, U. S. Army, City of Washington.

ization of vehicle construction without stagnation of unit design, if it can be stated that way, is desired. This feature has been clearly brought out by Colonel Taylor in the concluding portions of his discussion. It is therefore desired to invite particular attention to his table of standardization of military motor-equipment, which sets forth succinctly the thought underlying this principle. This proposition is thoroughly believed to embody one of the essential requirements for efficient motor-transport maintenance in military operations, and is presented as deserving of serious consideration by the automotive industry.

Service Simplified with Few Units

COL. EDGAR S. STAYER[5]:—The author emphasizes the importance of the maintenance problem and argues that it should be solved by design. The paper graphically portrays the necessity for this accomplishment, but only touches upon the scope of its possibilities.

Army experience gained along the Mexican Border in Texas and in the World War brought a realization that the maintenance problem must be simplified by simplifying design, and the development projected over the succeeding years points to but one way, to standardize and simplify military motor transport. This can be brought about through simplified practice and coordination between design, manufacture, operation and maintenance.

In obtaining a fleet of vehicles, it must be borne in mind that the assemblies must have the maximum interchangeability between component units. This is the basic principle of simplified maintenance. Efforts were made in this direction, and many possibilities unfolded as they progressed. It becomes apparent that a real solution of the problem of maintenance was in sight. In order that this scheme could be based upon experience, the components used were many and varied. From this accumulated experience it was pointed out that certain steps must be followed.

An operator of a fleet in an ordinary so-called commercial enterprise, bases his solution of the problem upon his experience in operation. By determining to limit his fleet to one or two chassis of one or two makes and taking advantage of the local maintenance service facilities of the manufacturers, the civilian operator considers that he has arranged for his maintenance. However, the civilian operator's experience is entirely different from the military problem of operating a fleet in time of War or emergency or in the peace-time training of the military establishment. If the civilian operator were called upon to move his fleet to a region where the manufacturers of his vehicles had no service stations and where no other service stations existed or if he were compelled to expand his fleet at a moment's notice, to be manned with untrained personnel, he could in a small way visualize the difficulties of operating motor transport for the War Department. Under such conditions he could not keep his fleet intact, and he would appreciate the problem of military motor transport.

World War Vehicles Were Too Diversified

Army motor transport requires vehicles of a diversity of types and capacities. If each type or capacity differs in make, then the maintenance problem will be as impossible of solution as it was in the World War, with constant wastage of funds and man power. It is well known that diverse makes were chosen during the World War, such as seemed best suited for the various jobs. The progress in development and capacities of motor equipment has opened up new fields for its use, and in a future emergency it will replace animal transport to an extent never reached in previous emergencies. Therefore the results to be obtained will depend to a large degree on the ability for continuous operation and simplified maintenance. The World War delays of multitudinous maintenance caused by lack of coordination of design, operation and maintenance must not be repeated; design, operation and maintenance must go hand in hand, with the objective of simplified and economical maintenance in a terrain remote from maintenance facilities. By design permitting a unit-replacement system, with interchangeability of units from various manufacturers made possible by standard installation dimensions, this efficient, economical and simplified maintenance will be obtainable.

The foregoing decision being agreed upon, the desired result can be accomplished by striving in time of peace to maintain a simplified design insofar as maintenance is concerned. And this will no longer cause the training of personnel to be a salient factor in the maintenance problem. This design for simplified maintenance will require only the minimum training of maintenance personnel in time of peace. In time of war or emergency, this personnel will be expanded to a very large extent, but less training will be required with the unit-replacement system than under the confused conditions caused by the procurement of diversified makes and types.

The foregoing can be easily accomplished by coordination of design, and one can readily see that the minimum amount of training will be required with the minimum number of units to be maintained.

Units Adapted to a Series of Vehicles

Considerable progress has been made along this line by development of experimental vehicles and from nearly two million miles of road-testing of these vehicles. Units for tests were obtained from commercial production that are satisfactory for military service; and when a satisfactory unit could not be found in commercial production, the commercial product was redesigned to fit the needs. The redesigned unit was then displayed to the commercial world, which invariably accepted it. In this selection of units that have been put into vehicles and that have been given a severe road test, simplicity has been the keynote and good workmanship has blended suitable materials into a product that has proved its ability. At the same time, the balance or desirable relationship of the units throughout the constructon of the entire vehicle has been given due consideration.

From the results obtained it is now believed that the vehicle based on selective units will be able to do what heretofore has not been done; that is, furnish a satisfactory motor transport for an emergency. These same vehicles will probably be found useful and satisfactory for commercial operation.

This experience has led to a program based on a limited number of units, which are designed or powered to form a maximum diversification in assembly. Powerplants have been selected whose ratings overlap throughout the range, and suitable provision has been made for the standardization of engine accessories. The number of makes of clutches and transmissions has been kept to the minimum, and the same can be said of all other parts that constitute the vehicle. The wheelbase has been altered, when necessary, to keep the number of different propeller-shafts as low as possible.

Axles have been developed that suit many types of drive. For example, the same axle suffices as the rear axle or axles under the six-wheel four-wheel drive or under the two-wheel-drive vehicles. Removing the brake mechanism and installing steering drive-ends will produce an axle suitable for the driving front axle under a multi-wheel-drive chassis. Subtransmissions have been developed with extended driving shafts that permit their use on any type of chassis. Wheels have been

[5]S.M.S.A.E.—Commanding officer, Quartermaster Corps, U. S. A., Holabird Quartermaster Depot, Baltimore.

selected that are interchangeable among all the different chassis and tires are used in series that are direct oversize of each other.

Adaptability Is the Result Secured

The foregoing practice continues throughout the component-unit construction of the vehicle, and it is interesting to note the outcome of these efforts. In a vehicle constructed as a six-wheel four-rear-wheel drive type, it was determined that the front axle could be removed and replaced with a drive type of axle. The front propeller-shaft is added and the same wheels and tires are used, thus changing the vehicle into six-wheel six-wheel-drive type within a few hours.

As this development progressed, a study of the maintenance situation was constantly kept in mind and a reduction of 60 per cent in the number of units to be maintained has resulted. This result is very pleasing to the personnel that is called upon to maintain transport, because the operating personnel will not think of it as a necessary evil, but as a "full brother."

The solution of the problem of economical transport in time of war or emergency consists in simplified design along the lines of easy maintenance and maximum interchangeability.

Applying Echelon Maintenance to Commercial Fleets

Capt. Walter C. Thee[6]:—The paper, especially regarding the echelonment of maintenance, places automotive maintenance on a sound, academic and scientific basis which makes possible satisfactory work at a reasonable cost. The analysis of the subject of maintenance simplifies and standardizes the service-manager's task to classify each particular job and do or have the job done in the most economical and efficient manner; that is, the five echelons of maintenance organize the various phases of repairs to motor-vehicles, which are usually classified as major or minor repairs, in a systematic and definite order.

The paper covers more than the author claims. The scheme of maintenance is not only admirably applicable for combat, for tactical supply transportation and for the general supply mission of the U. S. Army motor transport, but also for the problem of operation and maintenance of commercial transportation. It will be necessary, however, to modify the interpretation of the five echelons of maintenance for commercial practice according to the policies of different organizations. For example, the Army's system of having drivers and their assistants take part in minor maintenance is impracticable to the majority of commercial installations because of their higher moving factor, because of the imperfect discipline of commercial drivers, and because of their incompetence for such service.

For example, the first echelon is described as the vehicle-operator's maintenance. The title of this phase of the maintenance scheme should be interpreted by a commercial organization as merely giving a mental picture of the scope of repairs that should be made at this point. The work consists of cleaning, lubricating, servicing, tightening bolts and screws, and making ordinary running repairs and minor adjustments that can be accomplished with the tool-kit and the spares usually carried on the vehicle. In commercial organizations, when the moving factor of each vehicle is so high that it would be impracticable for the driver to perform these duties, the night crew consisting of garage mechanics and washers could be held responsible to correct any defects or requirements reported by the driver or observed by the maintenance or delivery superintendent during his periodical inspections.

But the second echelon, the organization commander's inspection, which corresponds to that of the maintenance or delivery-superintendent's inspection, need not be modified by commercial organizations. Periodical inspections and the correction of all defects noted is necessary for successful and economical operation. In the event that these two phases or echelons are neglected, vehicles will depreciate very rapidly and serious trouble will develop. Unless individual owners and small-fleet operators desire to have the vehicle driver make his own ordinary running repairs and adjustments and hold him responsible for the proper lubrication, this phase of maintenance will need to be "farmed out" to a local service-station or contractor. It would not be economical for individual owners or small-fleet operators to employ a mechanic or inspector-repairman unless there is sufficient work to keep him busy all the time he is employed. This is the solution of the problem of self-maintenance versus service-station maintenance, on which subject various papers and discussions have been published in the S. A. E. Journal.

The prescribed function of the third echelon of maintenance in commercial organizations is to make major repairs by removal and replacement of unit assemblies and exchange normally with the factory service-station or the fourth echelon; that is, unit-repair shops. This phase is carried out by operators of large fleets and in some instances by individual owners and small-fleet operators, depending upon the personnel and the equipment available. It cannot be denied that it is much more convenient to have unit assemblies repaired or rebuilt at some central repair-shop, such as a factory service-station, than at the local garage or service-station of fleet operators. The elements, namely, qualified personnel, supplies and adequate facilities and equipment necessary to accomplish major repairs by resorting to the third, fourth and fifth echelons, are greatly simplified. An ordinary hoisting device and a mechanic's tool-kit constitute the only equipment required by the third echelon.

Making major repairs by the unit-replacement system and ordinary running repairs, adjustments, inspections and periodic lubrication require little or no additional space beyond that required for garage purposes; therefore, they require little additional expense. Only "average" mechanics are required as personnel. The expert bearing men, cylinder and crankshaft grinders, are required only in the fifth echelon. Instead of large and costly stocks of supplies stored in the conventional stock rooms of fleet operators or service stations, all that is required in the way of supplies outside of parts common to the majority of vehicles is an exchange of the complete assembly.

Fourth and Fifth-Echelon Functions

The prescribed function of the fourth echelon in commercial organizations is to repair unserviceable unit-assemblies received from the third echelon by exchanging unserviceable subassemblies for serviceable ones that have been reclaimed or reconstructed by the fifth echelon. The factory service-station would correspond to the Army's fourth echelon. It involves a reserve stock of unit-assemblies and subassemblies, and a limited stock of spare parts. Attention is particularly invited to the fact that such reconstruction work as boring main-bearings, regrinding cylinder-blocks, crankshafts, camshafts, roller and ball-bearing cones and races, should *not* be done by factory service-stations or the fourth echelon. This type of work should be done in the most efficient and economical manner by the application of the fundamental principles of manufacturing management[7]. In some cases, however, there may be an exception to this rule.

In the event that a factory service-station has jurisdiction over a large enough territory where sufficient motor-vehicles of one make are concentrated, an ade-

[6] S.M.S.A.E.—Commanding officer, Quartermaster Corps, Second-Corps Area Motor-Repair Shops, U. S. Army, Fort Hancock, Sandy Hook, N. J.

[7] See S.A.E. Journal, August, 1930, p. 210.

quate supply of unserviceable units may be received throughout the year to keep at least one mechanic and one operator busy constantly on the performance of only one operation; that is, cylinder and crankshaft grinding, or the boring of main bearings and the like. In large cities and localities where organizations are located that specialize on certain work, such as regrinding cylinder-blocks and crankshafts, replacing worn bearings and boring them to proper size in mass quantities, the unserviceable subassemblies should be sent to such organizations provided that they employ specialized mechanics or trained drivers and have proper single-purpose-tool equipment and facilities. In such cases, the maintenance superintendent should investigate each organization carefully to determine whether it is applying the fundamental principles of manufacturing management, or mass production, and can perform the work as economically and satisfactorily as the organization that manufactured the unit or subassembly. The principles can be applied only when unserviceable subassemblies are reconstructed in mass quantities.

It is doubtful if local organizations can apply and adhere to all of the principles of manufacturing management; therefore, it will be necessary to ship the unserviceable subassemblies to the factory that produced them, or the fifth echelon. The factory service-station, or the fourth echelon, cannot economically employ specialized mechanics and install special time-saving single-purpose precision-tools unless the organization receives sufficient unserviceable subassemblies to keep them in operation constantly in the same manner as if the repairs were made by the manufacturer. These same principles apply also to the accessory units such as electric starters, generators, radiators, ignition units, oil, water and gasoline pumps, vacuum tanks, carbureters, windshield wipers, speedometers, gasoline and oil gages. No repairs should be made on these accessory units or, in fact, on any unit assembly by the first, second or third echelon; that is, by the individual motor-vehicle driver or by the maintenance or delivery superintendent of a large fleet of motor-vehicles, unless the work consists of ordinary running repairs and adjustments. These accessory units or any subassemblies may be repaired by factory service-stations where the fourth echelon of maintenance is applied, provided that sufficient quantities of similar unserviceable units are received to warrant mass production; otherwise, the unserviceable units that are economically repairable should be shipped to the manufacturer or to the fifth echelon.

Skilled Mechanics Not Needed

Attention is invited to the fact that the system of maintenance under discussion *does not contemplate using skilled mechanics at any stage of the scheme of maintenance.* Even in the fifth echelon, expert general mechanics are not used. Men are trained to operate special time-saving single-purpose precision-tools and are specially trained to perform one or a very few operations.[8] In the fourth echelon, or factory service-station, units are repaired by assembling subassemblies that were repaired or reconstructed in the fifth echelon, or the factory that originally manufactured them.

Motor-Vehicles as Applied to Military Use

A. W. HERRINGTON[9]:—Colonel Taylor has become an expert in the subject treated in his paper because he is a graduate of the hard school of practical experience. This field is so broad that it includes all forms of transportation with their proper coordination and employment. I emphasize those portions of his paper which, to my mind, apply particularly to the employment of automotive vehicles in the military service; namely,

(1) The military employment of motor-vehicles must always be considered as a mass employment; that is, as a centrally controlled utility serving the needs of the whole Army.

(2) That without the central control of both operation and maintenance, chaos would soon exist.

(3) During the World-War operations in France, the road conditions existing and the warfare of position were ideal for the use of motor-driven vehicles. It is extremely unlikely that these conditions will ever be duplicated in any other possible theater of operations in the world. Even with the large mileage of good roads available in our own Country, we still cannot approach the mileage of roads per square mile of territory that we had available for the American Expeditionary Force. Even were such roads available, the present developments in military air-weapons would assure their rapid destruction.

(4) That future military-transport vehicles must possess the maximum of "cross-country" ability and must combine with this ability all of the mobility that is now characteristic of our standard road-vehicles.

(5) That it is a patriotic duty for those who form the backbone of the automotive industry to acquaint themselves with the problems which the Army has to face, and to assist it in solving them.

C. M. BILLINGS[10]:—Regarding the 25,000 vehicles mentioned as being in one army in the World War, what was the size of that army?

LIEUT.-COL. BRAINERD TAYLOR:—We had a first, a second and a third army in the World War. Our first army, fighting in the Argonne, was being sent supplies for a million men. When they were active, the second and the third army were composed of many of the same divisions that were in the first army. The reference to 25,000 vehicles pertains to a normal field army, at war strength, of about 325,000 men.

Parallel Between Army and Commercial Plans

M. C. HORINE[11]:—From the viewpoint of operation and maintenance, I am particularly impressed with the strong parallel between the maintenance plans and requirements of the Army and those of commerce, and I believe that is one of the principal lessons that we can learn. It is only logical that the Army should have worked out a particularly effective scheme in view of the fact that Army motor-transport is almost entirely what we in commerce would consider under emergency conditions, where the requirements for effectiveness are correspondingly intensified. We who are engaged in the various branches and elements of commercial transport have a great deal to learn from the deep and protracted and highly informed experience which the Army has had. Although the term "echelon" is unfamiliar to us, the arrangement of the various maintenance functions as set forth by Colonel Taylor might well serve as a model to all large organizations of commercial transport.

Importance of Front-Wheel Drive

E. H. LAMBERGER[12]:—In the development of the use of four-wheel and six-wheel trucks suitable for cross-country hauling where there is no road, and mud holes are encountered, is the front-wheel drive essential? For a six-wheel vehicle having four-wheel drive, would

(*Concluded on p. 414*)

[8] See S.A.E. JOURNAL, November, 1927, p. 539.

[9] M.S.A.E.—President, Marmon-Herrington Co., Inc., Indianapolis.

[10] M.S.A.E.—Managing engineer, commercial-car division, Vacuum Oil Co., New York City.

[11] M.S.A.E.—Sales-promotion manager, International Motor Co., Long Island City, N. Y.

[12] M.S.A.E.—Railway engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Recent Developments in Poppet Valves

Discussion of A. T. Colwell's Semi-Annual Meeting Paper [1]

DISCUSSERS of this paper submit experience with various sorts of valve-seat material in aeronautic and other types of engine. Valves of motorcoach engines are said to operate under harder conditions than those of aircraft engines. Excessive heat is given as a cause of pick-up from the valve seats and even from valve-stem guides. A hope is voiced for a steel that is suitable for valves which will have thermal conductivity as good as that of ordinary carbon steel.

ROBERT JARDINE[2]:—Mr. Colwell's remarks on seat rings are of more interest to the users of motorcoaches and passenger-cars than to the users of aircraft engines, because the bronze valve-seats used in aircraft engines do run cooler than those made of steel or any of the alloys used in motorcoach engines. Our observation is that aircraft-engine valves operate under more favorable conditions than do motorcoach-engine valves. If the latter can be made to run as well as the former, we are quite pleased.

Seat rings made of ferrous alloys always seem to misbehave; cast-iron rings are better than the cylinder-block material only because they are more dense and close grained so that they resist wear better, but they are just as much subject to pick-up. This is eliminated only when ferrous alloys are discarded; it does not occur with bronze, Elkonite or Stellite, and it is not noticeably objectionable with high-speed tool-steel. High-speed steel is very satisfactory; the others may be better, but their cost is enough higher to cause serious consideration.

The great difficulty is to find something that will remain tight without elaborate retaining methods or insertion with the aid of liquid air. Inserted valve-seat rings seem to be quite satisfactory in L-head engines, but there is much more danger of their coming loose with overhead valves. What would help more than anything else would be to obtain a metal having substantially the same coefficient of expansion as has cast iron. Most of the good heat-resisting materials have too high a coefficient of expansion and are poor conductors of heat. They are compressed when they are heated and become loose when they are cooled. But for that, bronze would be very good in cast-iron cylinder-blocks. Bronze is used very successfully in the aluminum cylinder-heads of aircraft engines. I have seen aircraft-engine valves that have run for 300 hr. under full load without damage, some of them seeming to have worn smoother than at the start.

Valve seats that are made of a good heat-conducting material eliminate pick-up to a great extent, because the temperature is prevented from getting beyond red heat. Analysis of surface iron from the valve seat in a cast-iron cylinder after a hard run invariably shows it to be nothing but annealed cast-iron to a depth of several thousandths of an inch. I cannot see how that condition could be produced except by a surface temperature at the seats that is above red heat.

CHAIRMAN ARTHUR NUTT[3]:—Under certain heat conditions in the cylinder and with certain valve materials, bronze seats will pick up. Soft steels which have poor bearing qualities will pick up bronze. This condition usually can be remedied by making the valve seat to run cooler or by substituting a harder valve material.

G. C. BROWN[4]:—Valve-stems will pick up bronze, under some conditions, from guides of unsuitable analysis. I have observed several instances in which a change in composition of the guide has eliminated this difficulty.

The temperatures under which exhaust valves operate are usually quite high, and adequate cooling in the exhaust-port section of the cylinder-head is quite essential. It has been noted occasionally that a ring has been forged in the valve where it came in contact with the bronze seat, because of inadequate cooling of the valve-head. A change in the temperature conditions brought about an improvement, which seemed to indicate that the composition of the valve was satisfactory.

Improving the cooling usually betters the performance of the valve very much. In some liquid-cooled engines the coolant is not brought close enough to the valve seat to produce the desired effect, and valve trouble is the result.

Excessive Temperature Causes Trouble

ROLAND CHILTON[5]—Much of the discussion has illustrated a point that I have often emphasized. Whenever we find trouble in the design of any part of the engine, we turn to the material; we think that it would be better if the manufacturer would give us steel of better quality. However, we nearly always find the remedy, not by changing material, but by a change in the basic design which eliminates the cause of the trouble. Temperature is the basis of most of the difficulties that have been mentioned in this discussion. I am persuaded that almost all of the valve troubles, even including Ethyl corrosion, will disappear if we can reduce the temperature.

Some British engineers have told me that they could not use Ethyl dope in water-cooled engines which run on what we consider a relatively small degree of supercharging at ground level, and they could not understand how we could use as much as 3 cc. of lead per gallon, because they found it to cause serious corrosion. Cross-examination indicated that, without the Ethyl fluid, seat erosion was a worse trouble, because the temperatures were higher. The trouble was not with the Ethyl but the temperature, and I believe that the same is true of

[1] The paper was printed in the S.A.E. JOURNAL for July, beginning on p. 59. Mr. Colwell, who is a member of the Society, is chief engineer of Thompson Products, Inc., Cleveland.

[2] M.S.A.E.—Vice-president, Wilcox-Rich Corp., Detroit.

[3] M.S.A.E.—Vice-president of engineering, Wright Aeronautical Corp., Paterson, N. J.

[4] M.S.A.E.—Sales engineer, aircraft division, Bohn Aluminum & Brass Corp., Detroit.

[5] M.S.A.E.—Consulting engineer, Wright Aeronautical Corp., Paterson, N. J.

many of the difficulties that we have been discussing.

A. WILLGOOS[6]:—The work that Mr. Colwell and his company have been doing in cooperation with engine manufacturers to develop valves that are more suitable for high-duty performance is very commendable, and every encouragement should be given them. I am particularly interested in the valves with copper conductors. We have recently run an endurance test on a highly supercharged Wasp engine having valves with copper conductors, and the results show considerable promise.

It seems necessary, in view of the higher output that is being demanded of aircraft engines, to utilize the best possible means of valve cooling. It is highly important, particularly with internally cooled valves, to make the utmost provision for conducting the heat away from the guides, because the stems of internally-cooled valves naturally become hotter than plain stems. Providing a valve seat of generous width also aids in conducting heat away from the head of the valve.

The low thermal conductivity of the better valve steels is discouraging. Internal conductors might be dispensed with if we could obtain a suitable valve-steel having thermal conductivity as good as that of ordinary carbon steel. It is hoped that metallurgists may be able to accomplish this.

[6] M.S.A.E.—Chief engineer, Pratt & Whitney Aircraft Co., East Hartford, Conn.

Some Questions About High-Speed Driving

(*Concluded from p.* 368)

those difficulties I suggest a two-speed steering-gear, in which the gears are shifted by a small lever under the steering-wheel and, if necessary, interlocked with the transmission so that the low-speed steering-gear could only be used with reverse and low transmission speeds.

MR. HALE:—In a very interesting letter from Cannon Ball Baker he emphasizes in several places the importance of keeping both hands solidly on the steering-wheel and also, in high-speed driving, that the driver should always be on the alert and keep his mind on the driving.

We have much to learn about what we can and cannot do in high-speed driving, and then we must try to teach the people who buy these cars as much as we can, so that they will have the best possible information that we can give them on the limitations of driving. Nobody has a license to take the cars and drive them at the speeds at which they are capable of running without some form of instruction about the limitations of what is good and what is poor practice. I wish everybody would turn that thought over in their minds and see if, when they analyze their own driving, they really know what to do in cases of emergency and if they really are qualified to handle all situations without any question.

FAY L. FAUROTE[14]:—May I add something that came as a result of sitting on the Nassau County Grand Jury some months ago? We have a prosecuting attorney who is a very earnest advocate of safe driving and we have also the Sunrise Highway on which a number of cars are always going at high speeds. In the month that I served on the Grand Jury several cases of death caused by automobile accidents were investigated. These accidents all occurred from the same cause, *mental haziness* of the youthful driver. The brakes were O.K., the car was O.K., the road was good and conditions of lighting were usually good. The fundamental causes of these accidents were mental haziness, lack of experience, fatigue resulting from glare or driving on wet pavement, heedlessness on the part of delivery boys and intoxication.

[14] M.S.A.E.—Mechanical engineer, specializing in technical writing, New York City.

Carburizing with Gas in an Electric Furnace

(*Concluded from p.* 371)

MR. KOCH:—The hardness of nitrided steel below the surface drops very rapidly. The reason for the longer nitriding cycles is to build up the hard outside layer.

Small Parts Do Not Need Packing

CLEVELAND C. SOPER[5]:—What is the effect on uniformity of hardness when parts are piled promiscuously into the furnace?

MR. KOCH:—This has no effect on uniformity; the gas seeps in from the sides and causes uniform penetration. If flat plates are put together tightly, particularly if they are machined surfaces and are oily, the case would grade off.

MR. SOPER:—How should large rolls be stacked to secure uniform hardness?

MR. KOCH:—For such parts we probably would make a fixture or lay them on shelves; it is worth while to arrange the larger pieces, but small pieces can be merely shovelled into the basket. Parts like piston-pins get uniform penetration in that way; it is probable that variations would result from stacking them.

MR. SOPER:—Would the edge of one part coming into contact with the flat surface of another interfere with uniformity?

MR. KOCH:—We should prefer to separate such parts by a wire screen or anything else that will keep them apart enough to allow the gas to penetrate.

MR. SOPER:—How would you prevent hardening the bore of rolls?

MR. KOCH:—Probably the best way is to put conical caps on the ends to allow hardening the outer surface and ends and prevent access of gas to the bore.

MR. MUCKS:—Do you recommend local copper-plating to prevent carburizing?

MR. KOCH:—Carbonal gas will not penetrate copper-plating that is not porous. Some of the natural gases will penetrate copper-plating; then the only method is to block off the section that is to be protected or to use Carbonal. A surface of ceramic material might afford sufficient protection.

MR. MUCKS:—Is copper-plating effective on 5-per-cent nickel-steel?

MR. KOCH:—It has been used successfully in a number of cases on bevel-drive ring-gears of that material.

[5] Chief engineer, Firestone Steel Products Co., Akron, Ohio.

Reducing Fan Horsepower and Noise

Additional Discussion of A. D. Gardner's Semi-Annual Meeting Paper[1]

F. W. PAWLOWSKI[2]:—Mr. Gardner undertakes in his paper the rather enormous task of presenting an almost complete treatise on the helicoidal fan, something which is still waiting for a comprehensive and concise theory. Every engineer who is obliged to delve into this problem is thrown almost entirely upon his own resources in analyzing and interpreting the test results so as to be able to derive some general conclusions by which to be guided in his work.

The pioneering spirit should be encouraged; nevertheless, much human effort sometimes could be saved by the adoption or adaptation of a theory or methods already developed in some related field of inquiry. In this case, existing theories of propellers would serve as guides. The helicoidal fan may be considered as a special case of the screw propeller, being one of the 16 de Bothezat states[3] of propeller functioning.

How Fan Problems Can Be Simplified

In his very interesting and creditable paper, Mr. Gardner gave not only a rather complete analysis of the aerodynamical, mechanical and acoustical properties of his fans, but he also presented the results of some new and original discoveries.

Considering the interpretation of the aerodynamic properties of the fans, Mr. Gardner uses too many quantities as the dependent and independent variables, namely: (*a*) diameter of fan, (*b*) number of blades, (*c*) blade width, (*d*) angle of twist (projected width), (*e*) blade curvature (camber), (*f*) rotative speed, (*g*) air-flow velocity, (*h*) air pressure, (*i*) air volume per minute, (*j*) air volume per minute per horsepower, (*k*) power absorbed and (*l*) efficiency.

It is not to be wondered at, therefore, that he uses 17 diagrams, virtually each of them a family of curves, to represent the aerodynamic properties of his fans alone, and even then the story is not quite complete.

This reminds one of the situation in the older propeller theories where, in order to represent fully the five principal properties of a propeller (thrust, torque, useful work of propulsion, power absorbed, and efficiency), it was necessary to use five charts with five families of curves, since each property was treated as a function of two independent variables: the ratio of slip to pitch and the rotative speed.

With the advent and development of the Drzewiecki propeller theory[4] and the replacement of the aforementioned two independent variables by a single one; namely, V/nD or the advance-diameter ratio, the families of curves shrunk to single curves, so that one chart with five curves—for coefficients of thrust, torque, useful work of propulsion, power absorbed and efficiency, as functions of the advance-diameter ratio—fully represents both the properties of a propeller of a certain type, as determined by its geometric characteristics, and those of all propellers of any size that are geometrically similar to the prototype. Later, Gustave Eiffel, by means of his logarithmic propeller chart[5], has shown how a single curve—that of the coefficient of the power absorbed, with the efficiency marked along it—tells the whole story of all the propellers of a certain type. Finally, the aeronautical engineer of today, in fitting a propeller to a given craft, uses the curve of efficiency as a function of the advance-diameter ratio as the only and sufficient information about the type of propeller under consideration.

Apparently, Mr. Gardner could simplify greatly the presentation and interpretation of the aerodynamic properties of fans by utilizing these developments in the theory of propellers.

Comments on Exponents and Terms

Regarding the values of the exponents differing considerably from the theoretical values, such as 3 for horsepower and 2 for pressure as functions of revolutions per minute and 5 for horsepower as a function of diameter, similar discrepancies can be traced to observational errors or incorrect interpretation of the test results or both. One of the most common reasons for such discrepancies is the difficulty in ascertaining accurately the velocity of the flow of air and the density of air.

A function running to infinity, like that in Fig. 5 of the paper, should be avoided by changing the function or the independent variable.

Some of the terms used by Mr. Gardner are not satisfactory. The accepted terms for certain portions of a blade of a screw propeller are: leading edge, trailing edge, tip and root. The term "root of the blade" is quite appropriate in a typical propeller where the blades seem to grow out from what is called the boss of the propeller. In Mr. Gardner's fans, the blades look more like airfoils supported at their inner tips by the central spider-like affair. Since in an airfoil we distinguish leading edge, trailing edge, two tips, span and chord, in these fan-blades we may refer to outer and inner tips. At any rate, the term heel is not clear and is an awkward companion for the term tip.

Because of a certain tradition connected with the evolution of airfoils, including airplane wings and propeller blades, the width of an airfoil is called the chord, not the chord length.

Proper Meaning of Pitch

The notion of projected width seems to be superfluous, and the term pitch or projected width is confusing. These terms can be avoided by the introduction of the conception of pitch as used in screw propellers. While the dimensions named projected width at heel and at tip, in Fig. 2 of the paper, are of some interest in regard to the space required by the fan, they could be simply referred to as thickness of fan. The explanation of this term in the paper, on p. 113, seems to be based on an erroneous conception of the functioning of helicoidal fans.

---

[1] The paper was published in the August, 1931, S.A.E. JOURNAL, p. 109, and the discussion given at the meeting in the September, 1931, S.A.E. JOURNAL, p. 228. The discussion herewith was received too late to be included with that previously published. The author of the paper is chief engineer of the Automotive Fan & Bearing Co., Jackson, Mich.

[2] Guggenheim Professor of Aeronautics, University of Michigan, Ann Arbor, Mich.

[3] See the general theory of blade screws, by George de Bothezat, Report No. 29, National Advisory Committee for Aeronautics, 1918.

[4] See original papers by Stefan Drzewiecki in the transactions of L'Association Technique Maritime from 1892 to 1910. Essentials of the theory are given in The Design of Screw Propellers, by H. C. Watts, p. 334; Longmans, Green & Co., 1920 and Aircraft Propeller Design, by F. E. Weick, p. 37; McGraw-Hill Book Co., 1930.

[5] See Nouvelles Recherches sur la Resistance de l'Air et l'Aviation, by Gustave Eiffel, p. 60; H. Dunod et E. Pinot, Paris. See also plates 22-37, Report No. 14, National Advisory Committee for Aeronautics, by William F. Durand, 1917.

The disadvantage of this notion of projected width is evidenced in the paper as Fig. 10 gives the variation of air output with the projected width and the angle of twist, and neither the figure nor the explanatory text states whether these projected widths and the angles are taken at the "heel" or at the "tip" of the blades. Without such a statement, Fig. 10 is quantitatively meaningless. The smooth curves drawn through the experimental spots of Fig. 10 seem to have been unnecessarily forced to coincide at the origin of the coordinate system. A fan with cambered blades produces air-flow even when the "angle of twist" is zero; and it produces flow, and flow in the same direction, irrespective of the direction of rotation. The air-flow would become zero only at some negative "angle of twist," and what then would be the corresponding "projected width"? The experimental spots on Fig. 10 indicate quite clearly the tendency of all three curves to come down to zero at an angle of about minus 5 deg.

The use of the word efficiency with a meaning other than that generally accepted is very confusing and undesirable. The most important use of this word in engineering is for the ratio of output to input, of commeasurable quantities, in a transforming process or operation. Mr. Gardner calls efficiency the number of cubic feet of air per horsepower. While this is, in a way, a ratio of output to input, it would be better to compare quantities of the same kind. The reference to the "so-called spiral blade" seems to be an example of the too frequent confusion in engineering nomenclature between spiral and helical.

The consideration of blade width would be more interesting and informative if data were given as to the radii of curvature and the camber-chord ratio of the blades.

Counterflow Is Unimportant

Conditions in regard to discharge for a fan are not the same when the fan is working in free air and when it is back of the radiator under a hood. In the free air, the fan draws from all directions, and therefore a reversed and centripetal flow near the blade tips is possible and perfectly natural. However, there is no room and no reason for such a reversal of flow back of the radiator unless the louvers in the hood are too small for the escape of the air that is taken in through the radiator. Mr. Gardner's fears of considerable losses because of counterflow eddies or reversal of the flow seem not to be justified. Certainly the velocity of air-flow through a fan of the type shown in Fig. 2 of the paper cannot be uniform along the diameter, and there might be a slight reversal of flow near the center. This, however, should not be considered a serious drawback. It is possible to design a fan producing uniform flow across the entire area swept by the blades; but such a fan might be too expensive for production, because the blade of more complicated shape might be too expensive to produce.

The effect of unequal spacing of the blades is unexpected and most interesting. This is one of the valuable features of the paper. The section of the paper analyzing fan noises is very keen, and Fig. 20 explains the effect upon the noise of angular spacing of the blades most ingeniously. The fifteen general conclusions are interesting and convincing, with the possible exception of (2) and (5).

Should not the lowest slightly falling curve in Fig. 11 of the paper be marked 2000 cu. ft. instead of 2500 cu. ft.?

Information Designed for Motor-Car Engineers

A. D. GARDNER:—The primary object of the first part of my paper was to show the effect on fan performance of changing various features of the fan, so that a motor-car engineer who finds it desirable to reduce the diameter or projected width of a fan can determine from graphs what the effects will be on air-flow, horsepower, noise and other characteristics. The curves were designed to make such effects more evident than they would be if all the information were referred to the advance-diameter ratio.

That particular ratio has little significance in fan design, partly because fan designers have hesitated to adapt propeller-design factors to their fans, believing that the two are so unlike in purpose and construction that only confusion would result from such an adaptation, and partly because the factor V, the velocity of the airplane propeller through the air—or, in case of a fan, the velocity of the air into the fan—is not susceptible of ready measurement. No accurate measurements have yet been made, so far as is known, of air-flow under the hood of a car, and it is doubted if dependable measurements could be made of the velocity of the air leaving the core and entering the fan, which is the value V, in which we are interested.

We find the 17 diagrams with their families of curves essential to our purpose of explaining the characteristics of fans to engine designers, and to show them how their layouts can be made to retain the most desirable fan characteristics and to eliminate the less desirable, although the V/nD factor doubtless is of value in establishing the characteristics of airplane propellers and in simplifying the presentation of the theory of propellers.

Professor Pawlowski's comments are made purely with regard to airplane-propeller design, while the paper was written with regard to fan design and practice. There is a wide divergence here, but apparently there is some common ground in that the propeller may be considered as a special case of the fan. However, the conditions of operation are exactly opposite. The propeller is a course-pitched screw designed to exert maximum axial thrust and to displace as little air as possible rearward. The fan is designed to displace as much air as possible, while the axial thrust should be the minimum, for structural reasons. The efficient well-designed propeller of today makes a poor fan because of its low slip.

When an airplane is stationary, the slipstream from the revolving propeller seems to have a high velocity and the volume of air moved seems to be enormous. However, if a cooling-fan of conventional type could be installed and made to utilize the same power input as the propeller, the velocity of the air from the fan would be much higher and the volume of air moved would be several times greater; the cooling-type fan displaces more air to the rear per horsepower consumed than does the airplane propeller.

"Pitch" Has Special Meaning for Fans

The use of the term pitch in connection with fans is unfortunate, since its meaning is entirely different than for propellers. It has never had any meaning in the fan industry other than the projected width of the blade along the axis of rotation; it has no relationship to any other design feature.

For a propeller, the definition of geometrical pitch, as given in the nomenclature issued by the National Advisory Committee for Aeronautics, is the distance which an element of a propeller would advance in one revolution, if it were moving along a helix of slope equal to its blade angle. The N.A.C.A. definition of effective pitch is the distance the airplane advances along its flight path per revolution of the propeller. The propeller slip is the difference between the mean geometrical pitch and the effective pitch, and it may be expressed as a percentage factor of the mean geometrical pitch or as a linear dimension. Slip is a measure of propeller inefficiency and depends on design characteristics and operating conditions.

For a fan, the projected width of the blade repre-

sents the thickness of a disc of air which each blade slices off and displaces to the rear during one revolution. This relationship holds true at low speeds; but the air-flow is greater at high speeds than this would indicate, because of, first, a flow of air through the radiator core or in the wind-tunnel that is induced by velocity and, second, kinetic energy applied to the air-stream by the impact of the blades, resulting in increased dynamic and static pressure on the pressure side of the blades. In the case of multiblade fans, interference between blades causes an opposing tendency. The multiblade fan creates a greater pressure, but the flow per blade per revolution is not as great as for a fan with a smaller number of blades.

Considering the fan as a propeller and applying propeller nomenclature to it, the geometrical pitch of the four-blade fan shown in Figs. 3, 4 and 5 of the paper is calculated to be 21.8 in. The results of tests in the wind-tunnel, as shown in these figures, indicate an advance of air through the wind-tunnel of about 7.4 in. per revolution at a speed of 2000 r.p.m. The slip of the fan would therefore be 7.4 in., and the effective pitch would be 14.4 in. From this example it may be seen that a large percentage of slip is desired for maximum fan discharge.

The figure 7.4 in. might be said to be the "effective projected width" of the fan. While the effectiveness of the propeller is denoted by the absence of slip; the effectiveness of the fan is denoted by the presence of slip, which may be said to be the difference between the "geometrical projected width" and the "effective projected width." Loss of efficiency in a propeller is evidenced by slip; in a fan, by noise, disturbed air-flow, eddy currents, counter air-flow and increased horsepower.

However, it is to be deplored that the fan industry has taken so little advantage of the vast amount of research and development work done by the airplane industry on propeller characteristics, particularly with respect to the flow of air across airfoils, the static and dynamic pressures in the vicinity of the propeller blade, the power absorbed and the relation between thrust and slip.

The fan dimensions which are of primary importance to us are diameter and projected width. The latter is usually referred to as pitch, which is a misnomer; it is not the same as the term pitch as used for propellers. In practice, substituting the term thickness of blade for projected width would lead to confusion and would be taken to mean the thickness of the blade material.

The curves in Fig. 10 are plotted between projected width and air output. The angle of twist is found from the relationship, projected width equals the chord times the sine of the angle of twist. The text states that the same fan was used in obtaining these data as was used in previous tests. Reference to the description of Figs. 6, 7 and 8 shows this fan to have a diameter of 18 in. and a projected width of 1½ in. It should have pointed out also that all the tests up to and including those referred to in Fig. 10 were made with a fan of the same dimensions and that the projected width was 1½ in. at both the heel and the tip. No tests on spiral blades were covered in this portion of the paper.

Spiral and Helical Fan-Blades

The type of blade discussed in the foregoing is merely a section of the surface of a cylinder. If this blade, retaining the same radius of curvature, were twisted so that the chords did not lie in a single plane, the angle of twist at a given section being proportional to the distance from the inner end of the blade, it would become a helical blade. The so-called spiral blade is formed in the same way except that, before twisting, the blade is a section of the surface of a cone. The radius at the heel is smaller than at the tip; and the projected width is greater, for a rectangular blade. Leading and trailing edges, if parallel in the blank, become spirals, as does also the center-line of the blade.

The camber-chord ratio is a convenient method of specifying blade curvature and width; but it has not been widely adopted in the fan industry, because radius of curvature and blade width must be specified in order to build the necessary dies for forming the thin sheet-metal into a curved fan-blade.

Counterflow Is Important

Counterflow at tips of blades results in recirculation of the air by the fan, decreasing the induced flow through the core and consuming horsepower uselessly. This is particularly true if the fan is more than ¾ to 1½ in. from the core, unless a shroud is used. The condition is aggravated if the hood louvers are placed too far forward, allowing an air stream inward through the forward louvers that vitiates the induced flow through the radiator core. Even without interference from improperly placed louvers, counterflow at tips of the blades greatly reduces the flow through the core and results in a rise in top-tank temperature of 3-5 deg. fahr. when the fan is placed 1½ to 4 in. away from the core.

As pointed out by Professor Pawlowski, the lowest constant-airflow curve of Fig. 11 should be marked 2000 cu. ft. instead of 2500 cu. ft.

The Diesel Designer's Problem

SOME PHASES of the problem of Diesel-engine development seem, from a broad engineering viewpoint, not to have been given sufficient consideration. Too much of the development has been predicated upon the tacit assumption of a large price differential in favor of Diesel-engine fuels. In the meantime, revolutionary changes have come about in the production of petroleum products in the refinery, and Diesel-engine progress has indicated that fuels for small high-speed engines must be refined products.

As a result of these developments, there is now no long-time prospect of a great price differential between fuels for Diesel engines and those for gasoline engines; in fact, refinery processes are capable of yielding any grade of fuel demanded, without much regard to volatility, at prices not greatly different. Therefore the Diesel-engine designer must predicate the development of his business on the inherent advantages of the Diesel engine over other types without much regard to fuel price.

The possible advantages are lower fuel consumption, that is, greater thermal efficiency; increased safety, which is particularly important in aircraft and motorboats; greater simplicity; freedom from electrical appliances; overload possibilities; and, of course, cost of construction. If the designer can demonstrate sufficient advantages along some of these lines to justify the change from the Otto cycle to the Diesel engine, he can present a sound foundation for commercial development.—Dr. H. C. Dickinson, in discussion at a meeting of the Cleveland Section.

The Place of Industrial Trucks in Automotive Materials Handling

Discussion of C. B. Crockett's Milwaukee Production Meeting Paper [1]

IN THE DISCUSSION questions are asked regarding the relative merits of gasoline and electric trucks, the comparative cost of operating them, why they cannot be produced by mass-production methods and if there is not a good field for small, narrow-gage trucks for getting through narrow aisles and around factory machines. The author discusses each question in some detail, giving in his replies useful information which supplements that contained in his paper.

CHAIRMAN CYRUS L. COLE[2]:—One thought occurs to me which concerns just a little simple arithmetic. A laborer with a wheelbarrow or two-wheeled truck has about all he can do to move a load of 500 lb. One of these small industrial trucks that Mr. Crockett showed will travel at three times the pace of the man with the wheelbarrow or two-wheeled truck. Theoretically, therefore, as a beginning in the reduction of costs, we have the ratio of 24:1, just for a 2-ton truck; and it is brought to your attention that trucks are being built in sizes up to 17½-ton capacity.

Gas and Electric Trucks Meet Different Needs

P. C. RITCHIE[3]:—Has Mr. Crockett any figures showing the relative merits of gasoline and electric power for these industrial trucks?

C. B. CROCKETT:—The fields of the gasoline and the electrically driven machines should not be confused, and the operating costs of a gasoline-driven piece of industrial equipment should not be compared with the costs of operating a passenger automobile. A passenger-car powered with a four-cylinder engine, after having been driven 35,000 miles, is in a condition to require considerable overhauling and repairing. Assuming an average driving speed of 25 m.p.h. and bearing in mind that probably a good deal of that is done at high speed, the engine operating hours are in the neighborhood of 1300.

Gasoline industrial trucks are sold to a great extent for 10 to 16 hr. operation per day, and when the engine is started in the morning it continues to run almost the entire day. Moreover, the truck is repeatedly stopping and starting and, because of the drive ratios, the engine makes more revolutions for the distance traveled than does that in the passenger-car. Dividing 1300 operating hours by 10 hr. per day gives 130 days; so in 130 days a gasoline-driven industrial machine is given as much wear and tear as an automobile is given in driving 30,000 miles. Therefore, to compare the yearly operating costs gives a very erroneous conclusion.

In the second place, the gasoline machine has high-speed continuous operation and long hauls and goes over bad floors and through badly paved yards. Every one of those factors raises the cost of handling operations and consequently the cost per ton, regardless of the type of equipment used. If a type of equipment having characteristics that make it suitable for expensive handling operations is used, those characteristics must be paid for even if the equipment is used for short hauls over good floors and is operated under circumstances which favor the electric. If a difficult handling operation is overcome with one type of equipment, it will cost just as much to operate that type of equipment where you do not have those conditions.

In most cost studies, the factors involved in any particular installation are so varied and so complex that it is almost impossible to draw any conclusions. In a survey made by a well-known engineering company a comparison has been made between gasoline and electric equipment. It shows that the operating cost of the gasoline equipment was in the neighborhood of 40 cents per hr., not including driver's wages, and that of the electric equipment was 78 cents per hr.

A fact not stated in the survey is that the gasoline equipment was only 6 months old while the electric equipment was from 7 to 14 years old. The survey showed a cost for electric power of 16 cents per hr.; it did not state that the entire electric bill on the pier where the equipment was used was being charged against the electric trucks, although some of the current was used for lighting. The survey did not show that the cost of current was 7 cents per kw-hr., which is the lighting rate. Actual figures on a comparable basis showed the hourly cost to be 55 cents per hr. for the gasoline truck and 39 cents for the electric.

That is the type of comparison which makes the drawing of conclusions about gasoline and electric equipment dangerous. It is almost impossible, even on the same operation, to continue the test long enough to give an accurate result, because a 6-month test will give one figure and an 18-month test will give a very different figure. So the relative merits of the two types of equipment might be summed up in this way: If the electric can do the job, the operating cost probably will be lower than with gasoline trucks, but to put electric trucks on jobs that they cannot do would be foolish; those are the ones for the gasoline equipment.

Diminutive Truck Presents Problems

EUGENE BOUTON[4]:—Most of the trucks shown in the pictures are the heavy-duty type. In the last two or three years several types of small, narrow-gage trucks

[1] The paper was published in the S.A.E. JOURNAL, August, 1931, p. 158. The author is secretary of the Industrial Truck Association, New York City.

[2] M.S.A.E.—Vice-president, engineer, Williams, Cole & Wolff, Inc., Milwaukee.

[3] A.S.A.E.—Advertising manager, Waukesha Motor Co., Waukesha, Wis.

[4] M.S.A.E.—Supervisor, time study, J. I. Case Co., Racine, Wis.

have been built for getting through aisles and around machines. That type of truck offers as much economy in material handling, I believe, as the larger trucks.

MR. CROCKETT:—I think that the small truck has a very definite field. It presents an engineering problem to design a truck that is small and compact enough and at the same time capable of carrying a large enough load to warrant the investment. Machines are now built that are less than 27 in. wide over-all and which can make a right-angle turn, I believe, with a skid, in a 52-in. aisle. One of the difficulties in the small plant is that the capital investment becomes more and more of a factor in the installation the smaller the size of the plant is.

Huge Variety Prevents Mass Production

CHAIRMAN COLE:—Will you explain why these industrial trucks cannot be produced by mass-production methods?

MR. CROCKETT:—The development of industrial trucks has been in three directions: (*a*) very large machines for heavy loads; (*b*) very small, compact machines for operation in congested areas, but which are capable of handling 2000 to 3000 lb. per load; and (*c*) special machines. There probably are five or six standard types of truck which differ radically in construction. These are the platform-carrying, the low-lift and the high-lift or tiering trucks, the tractor, the crane, and now, I believe, the fork-type industrial truck is almost recognized as one of the standard types. Capacities range from 1 to even 15 or 17½ tons.

Therefore, we have six or seven capacities, five or six standard types and also an innumerable number of modifications and attachments. From a survey recently made we estimated that there are at present more than 900 distinct modifications and adaptations or attachments to standard trucks. The solution of special problems by means of special machines probably is the tendency throughout the industry. The maximum production of these machines is less than 2000 per year, manufactured by some 10 companies. Obviously, therefore, the economic possibilities of mass production in this industry are remote; hence most of the trucks are handmade, virtually assembled to specifications and with a consequent high cost compared with products of the automobile industry.

Relative Cost of Operating Power

JAMES G. ZIMMERMAN[5]:—What is the cost of power in the operation of the electric and the gasoline truck as compared with the total costs?

MR. CROCKETT:—The question of power costs involves the rate of current per kilowatt-hour and the cost of gasoline in the locality. The average gasoline machine consumes about 0.7 gal. of fuel per hour of operation. On a 10-hr. operation, it would use 7 gal. at, say, 12 or perhaps 15 cents per gal. That amounts to $1.05 a day for fuel, with probably 15 cents more for oil, which would make the cost for gasoline and oil $1.20. That compares with average kilowatt-hour consumption at the incoming end of the charging equipment of approximately 22 to 25 kw-hr. per day. I suppose that in industrial territories the average rate for industrial current is about $0.015 per kw-hr.

Electric-truck charging does not add any load to the peak demand of the plant, but comes automatically on the lowest step of the power rate, if the plant is operating on a decreasing rate, which is common with most power companies. Therefore 22 kw-hr. at 1½ cents per kw-hr. is about 33 cents per day for electricity, as compared with $1.20 for gasoline and oil.

That is not a fair comparison, however, because the gasoline tank in the truck does not enter into operating cost whereas the battery for electric power does cost something. In comparing power cost, one should compare the cost of gasoline and oil with the cost of electric current plus battery maintenance and depreciation. A battery costs in the neighborhood of $100 a year, which, divided by 2400 operating hours, would give about 4 cents per hr., or, on a 10-hr. day, about 40 cents a day. Adding that to 33 cents, the cost of current, gives about 73 cents as the total cost of power for the electric as compared with probably $1.25 for the gasoline truck.

But even a comparison of two machines on the basis of daily costs is erroneous, unless the foot-tons of material moved by each machine is taken into account. If the hauls are 500 to 600 ft. one way or longer, the gasoline truck will probably do more work in a day than the electric, because of its high speed; therefore, the length of hauls and whether advantage can be taken of the high speed of the gasoline machine must be taken into account. If the electric and gasoline machines can be operated side by side and the tons moved per day are recorded, then the daily costs can be determined. If the hauls are long, the greater capacity of the gasoline machine almost exactly balances the disadvantage it has in power cost; on shorter hauls the advantage of speed is lost, and the electric machine realizes the advantage of perhaps 50 cents per day in power cost.

[5] M.S.A.E.—Research and consulting engineer, Madison, Wis.

Aviation's Future in Canada

THE FUTURE of aviation in Canada is full of promise. No country in the world needs aviation more than does the Dominion. The work that is being done yearly in the far north and in the great timber forests of this country is difficult to value in dollars and cents, but every penny that has been spent upon flying by our Dominion and provincial governments has already been returned many times over by the results obtained. This work is fraught with great dangers but has been carried out successfully with the same spirit with which our Canadian pilots flew during the World War. The layman hardly can imagine the hardships and dangers of those long flights in bad and severe weather over the unsurveyed tracks of the northern country.—From an address by Lieut.-Col. W. A. Bishop before the Canadian Section.

Carbureter Design for the C. F. R. Detonation Engine

Semi-Annual Meeting Paper

By C. S. Kegerreis[1]

ACCURACY of metering and speed in manipulation are the two prime requisites in a carbureter for detonation-measurement work, according to the author, who outlines briefly the development, for use with the Cooperative Fuel-Research Committee test engine, of an instrument based upon the Dobbs carbureter designed by the Anglo-Persian Oil Co. for detonation testing.

As now manufactured for routine testing, the device consists of four float-bowls having entirely separate air and fuel channels, the channels from each bowl being controlled by individual air and fuel valves that operate in unison. The throttle, which is of the barrel type, is operated by a worm and gear and has an indicator arm attached to facilitate duplication of throttle settings. Results of tests indicate that this carbureter is satisfactory over a range from 40 deg. fahr. to the point at which gassing of the fuel becomes objectionable. Special nozzles can be provided for fuel densities outside the normal range.

DESIGNING carbureters for single-cylinder engines presents a different problem than designing them for multi-cylinder engines. In addition, if detonation is to be measured, the metering must be more accurate, as the same adjustment for operation must be repeated over and over. Constancy of mixture-ratio at the various engine loads at constant speed is desirable. Of more importance, however, is the ability to duplicate any one mixture-ratio or any one engine-operating condition. This necessitates a thorough mixing of the fuel and air so that all combustion strokes will more exactly deliver the same detonation value, although we realize that, in an internal-combustion engine, the optimum in this last objective cannot be realized.

Accuracy of metering is of a somewhat lower order in commercial carbureters. Maximum power is developed over a broad mixture-strength range. Maximum thermal efficiency is developed over a range that is somewhat narrower yet is sufficiently broad that a variation of between 5 and 8 per cent is permissible. For measuring detonation, a maximum variation of 0.02 or 0.03 ml. per min. in the gas-evolution readings is permitted. As this requires an accuracy of metering within 2 to 3 per cent, extreme care must be exercised with each element in the design of such a carburetion instrument.

Manifold Design

Experience has taught us that long manifolds cause irregular operation or surging as regards engine speed, particularly if wet mixtures are used. This condition is improved if these manifolds are heated. Preliminary tests proved conclusively that, the shorter the distance is between the valve and the carbureter nozzle, the more constant is the speed. To determine this factor, the worst possible condition that could probably be encountered in the operation of the C. F. R. test engine was checked. Tests made at 40 deg. fahr. proved that manifolds longer than 3 to 4 in. gave unsteady operation. On the L-head engine, a short downdraft manifold was entirely satisfactory. The velocities were kept reasonably high and, with the port walls warm, no excessive puddling was experienced. These tests were made with a fairly low-grade fuel rather than with some of the better grades and showed no need of preheating the air or mixture.

Cold operation is very essential because of vapor and air-lock conditions experienced in carbureters. Small bubbles occurring in fuel channels, particularly ahead of the fuel restriction, result in erratic metering. The refrigeration that occurs in the carbureter aids in keeping this vapor condition at the minimum.

Range of Adjustment

A broad range of adjustment is necessary for accurate testing. A simple needle-valve in the fuel channel is entirely too sensitive for test work with small fuel-consumptions. This valve will normally be open only $\frac{1}{2}$ to $\frac{7}{8}$ of a turn. Any clearance in the threads or inaccuracy of the needle and orifice will aggravate this sensitiveness. Usually an air bleed is not so sensitive, consequently building a carbureter of some design that could be adjusted by the air-bleeding method, rather than operating directly on the fuel-flow, seemed desirable. This was particularly observed by Dr. H. C. Dickinson during his visit to England, where the Anglo-American Oil Co. had developed such an air-bled carbureter for its use in detonation-measurement work. With this in mind, the Bureau of Standards constructed a trial installation and found that a range of adjustment of between two and three turns was allowable for mixture ratios giving maximum detonation and with sufficient range on each side of the peak.

A longitudinal section through the Dobbs carbureter, as built in the laboratories of the Anglo-American Oil Co., is shown in Fig. 1. The carbureter consists of two float-bowls having a common fuel-jet that is capped at its discharge end by an air-bleed passageway. An adjustment is placed at the air inlet to regulate the volume of air bled over the end of the fuel jet. The exits of both jets are at the venturi throat. In this particular design the air adjustment is shown by a radio dial and indicator. The butterfly throttle-valve is adjusted and its position measured by the same means as the air bleed.

The adaptation of this carbureter with an extremely short manifold and the minimum distance between the butterfly throttle and the nozzle gave pleasing results with a single float-bowl mounted on the L-head engine.

In view of this preliminary work, a detailed study of the research and routine-testing factors was made.

[1] M.S.A.E.—Consulting automotive and mechanical engineer, Toledo, Ohio.

Speed in testing is of prime importance in regular routine work, and, to attain this, two float-bowls are absolutely necessary, and two other bowls to carry additional reference fuels are desirable, each bowl being a carbureter in itself. Thus, once an adjustment is made on a definite fuel, a switch-over is made to the next fuel in order and its maximum - detonation point measured. When this is accomplished, the switching from one carbureter to another for checking is quickly effected. Therefore, as originally proposed by D. B. Brooks, the carbureter design took the form of four separate carbureters having a common air-and-fuel channel and a common mixture passageway with a common throttle. Various attempts were made in the arrangement of these associated bowls for ease of control and symmetrical placement. To assure the minimum length of fuel passage, the downdraft type of carbureter was chosen. To care for the research installation requiring only two bowls, the main fuel-and-air passageways were built around them. For the routine-testing type, the two additional bowls, with the requisite connecting passageways, were designed. Thus, if a research type only is purchased, the auxiliary bowls for routine testing can be added at any time. The initial design of this carbureter is illustrated in Fig. 2 and that of the four-bowl, or routine-test type, in Fig. 3.

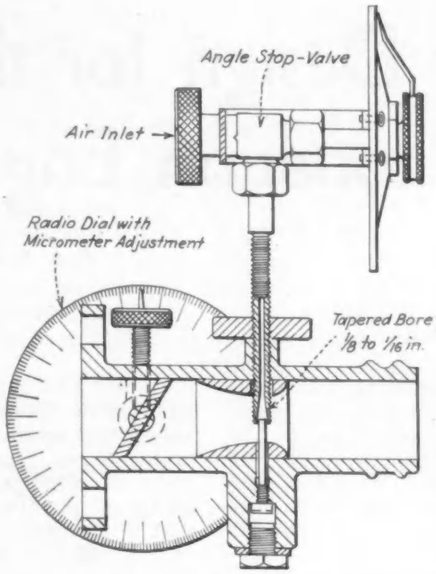


FIG. 1—LONGITUDINAL SECTION THROUGH THE DOBBS CARBURETER

This Device, Which Was Developed by the Anglo-American Oil Co., Consists of Two Float-Bowls Having a Common Fuel-Jet That Is Capped at Its Discharge End by an Air-Bleed Passageway

Complete testing of this one instrument proved that better operation was accomplished by reducing the manifold diameter; also the mixture passageway was considerably reduced, with more pleasing results. The departure from commercial sizes of carbureter is a reduction in diameter from 1 3/16 to 15/16 in., mainly because the standard speed of this test engine is 600 r.p.m. Further checking showed that the butterfly valve was extremely sensitive to throttle position or angle.

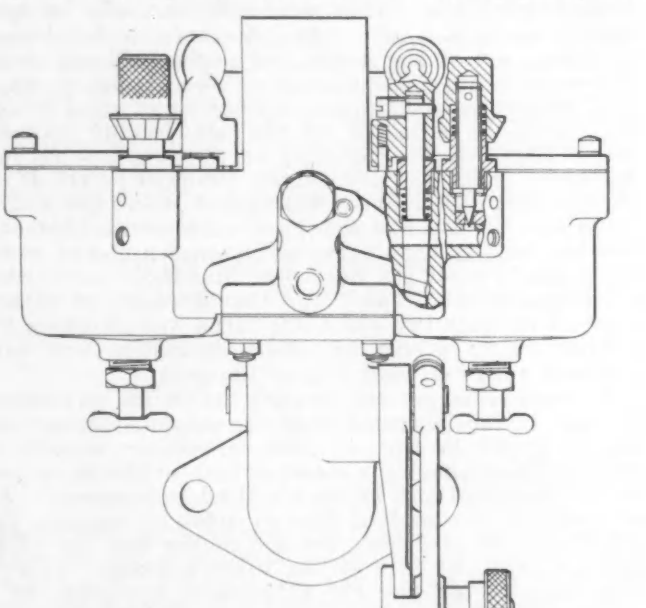


FIG. 2—FIRST DESIGN OF CARBURETER FOR DETONATION TESTING WITH COOPERATIVE FUEL-RESEARCH ENGINE

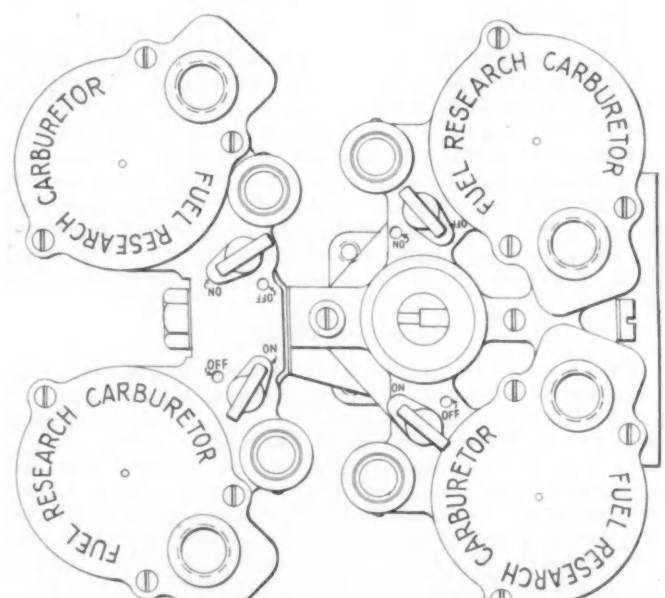


FIG. 3—PRELIMINARY DESIGN OF ROUTINE-TEST TYPE OF CARBURETER WHICH HAS FOUR FLOAT-BOWLS

Reducing the Manifold Diameter Was Found, after a Complete Test of the Instrument, To Improve Its Operation. Better Results Were also Secured by Substantially Reducing the Mixture Passageway

Proposed Design

Following criticisms and suggestions from various sources, the preliminary design was changed to that illustrated in Fig. 4. The air horn was lengthened to prevent fuel from spraying back from the air-horn entrance, more easily operated switch-over cocks were installed and the throttle was changed to a barrel type operated by a worm and gear to relieve the sensitivity of the adjustment. The new construction required 13 turns of the throttle knob to rotate the cylindrical barrel through its full opening. An indicator arm operated by the throttle shaft was placed on the throttle quadrant to more readily repeat the throttle position. Several other minor details were changed, as will be observed by careful comparison of the preliminary design with the later designs.

To assure reliability of performance, 10 experimental carbureters were built for checking. Exact duplication of performance in a commercial field is difficult, especially in the case of a detonation instrument. Information accumulated from the 10 devices showed erratic operation, duplication of results even in the same carbureter being difficult. The trouble finally was located in the conical switch-over cocks. The smallest scratch

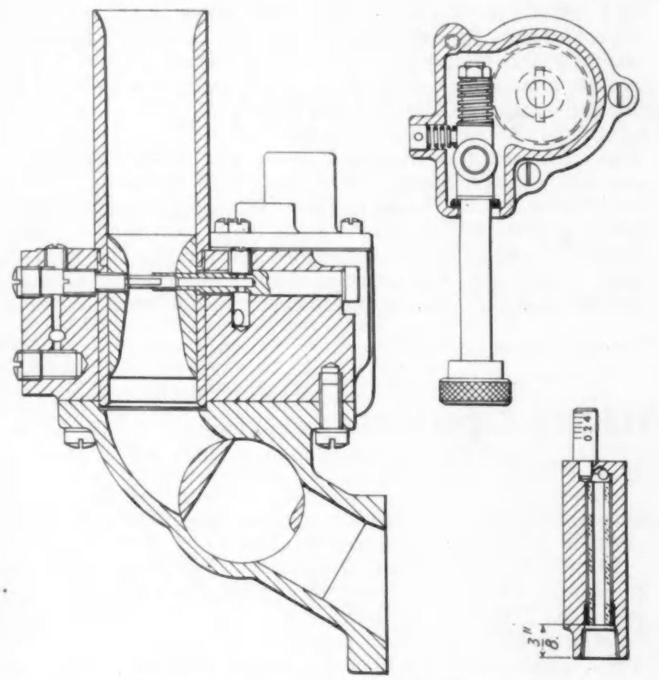


FIG. 4—SECTIONS THROUGH THE MIXTURE PASSAGEWAY AND THE THROTTLE-OPERATING MECHANISM OF A MODIFIED FORM OF THE DESIGN SHOWN IN FIG. 2

Besides Reducing the Mixture Passageway, the Air Horn Was Lengthened To Prevent Fuel from Spraying Back from the Air-Horn Entrance. The Throttle, Which Was Changed to a Barrel Type, Is Operated by a Worm and Gear, 13 Turns of the Throttle Being Required To Rotate the Cylindrical Barrel to the Wide-Open Position

or the least particle of dirt in the channels would cause sufficient scratching of the body or taper plug to allow fuel leakage around the cock itself or else into the air-bleed passageway. The design was so simple that we hoped some method could be devised to use this taper type of cock, but the results remained satisfactory only for a short period; therefore an entirely new type was designed to replace the defective valves in the first 10 experimental carbureters. Separating the fuel and air channels by diaphragms and using needle-valves for the fuel gave results that were more satisfactory over a long period.

The diaphragm valves were objectionable, however, because of (*a*) the mechanical complications and (*b*) the difficulty of production and the increased cost. Finally, the air and fuel channels were completely separated, with individual valves for each fuel and air channel. To simplify the operation, one fuel and one air valve were operated simultaneously.

The present design, with the changes incorporated, is illustrated in Fig. 5, which is a plan view of the routine-test type, details of the fuel valve and its companion air-bleed valve being given in the small insert. The fuel valve is simply a stainless-steel needle held on its seat by a suitable spring and placed as close as possible to the fuel-metering jet to decrease the length of the fuel channel. The air valve consists of a lapped stainless-steel cylinder operating as a gate-valve to open and close the desired air-bleeding passageway. Lifting this gate-valve also raises the fuel valve from its seat, the two thus operating as a unit. The fuel channels are longer than desired, but no design meeting all considerations was possible. Little trouble will be encountered if care is taken to remove all air bubbles periodically.

General Results

Operation of the carbureters shows an adjustment range of two turns when using ordinary gasolines, but the lighter gasolines will have this effective adjustment decreased. However, detonation can usually be carried to a 50-per cent value on either side of the power peak. The detonation peak will not always come at the same carbureter adjustment for the same fuel, owing to slightly different restrictions in the air passageways from each bowl and also to the small change in float level.

The actual value of the maximum-detonation point usually checks within three points on the gas scale. The knock-meter readings should usually check to a closer value, particularly near the 50-per cent region on the meter scale. This is because the knock-meter-scale increment decreases with the higher knock values. If the detonation values do not check within this limit, either dirt or vapor bubbles are present somewhere in the system.

Vapor was always encountered throughout the investigations whenever long conduits were used; hence the fuel containers must be mounted directly above the carbureter float-bowls. A small change in level will change the detonation value, and air bubbles in the supply line will readily disrupt the flow to the carbureter bowl and consequently cause this condition. The higher the gasoline volatility is, the more carefully the operator must check the vapor conditions.

The fuel nozzle supplied will provide an adequate range of mixtures from most gasolines. In cases in which the correct adjustment range cannot be attained, smaller jets can readily be installed. All thread sizes are standard, consequently any machine shop can readily supply any threaded parts.

Service on carbureters supplied to distant geographical points is cared for in this way: Standard carbureter parts, screws, floats, needles and seats are purchased from manufacturers having service stations in the more important countries, hence replacement parts can be purchased readily without the usual delay necessitated by special parts. The worm and gear also are of standard manufacture, so that whenever wear becomes a factor these can readily be renewed.

The float levels are indicated by a gage glass mounted on a carbureter bowl. The actual float level is 19/32 in. below the top of the bowl. The gage-glass graduation

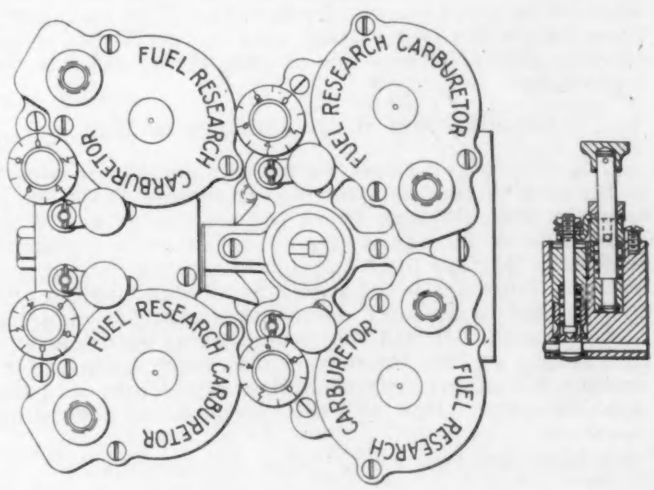


FIG. 5—PLAN DRAWING OF THE ROUTINE-TEST TYPE AS FINALLY DEVELOPED

This Shows the Air-Bleed Adjustments and the Valve Arrangement. Details of the Fuel Valve and Its Companion Air-Bleed Valve, Both of Which Are Operated Together, Are Given in the Vertical-Section Drawing at the Right

is ½ in. The 3/32-in. difference is due to capillary action in the gage tube. Consequently, in resetting float levels, the ½-in. dimension must be used instead of the 19/32, as listed on the drawings. In checking the same fuel in different bowls, these levels must check within 1/32 in.; otherwise the float level is not of serious import.

Conclusions

This instrument is believed to be satisfactory for general detonation testing. The temperature range can extend from 40 deg. fahr. to the point where gassing of the fuel becomes objectionable. The throttle is less sensitive than the butterfly type, and, if found objectionable in the present design, can be changed by altering the shape of the throttle barrel. Fuel nozzles can be changed to provide for fuel densities outside the normal range. Channels are provided with plug screws to facilitate cleaning with air or flushing with fuel. The carbureter is expected to be sufficiently flexible to operate satisfactorily under the wide range of testing conditions encountered. The design has been hurried and many details no doubt have been neglected. Consequently, criticisms are welcomed so that, in the final design, nothing of importance shall have been overlooked and the device will operate satisfactorily to all.

Motor Transport in Military Operations

(*Concluded from p.* 403)

Colonel Taylor consider it essential to have the front two wheels instead of the rear two wheels driven?

LIEUTENANT-COLONEL TAYLOR:—We have been experimenting with driving on the two rear axles; but, in our recent developments and in our first great purchase of about 120 5-ton and 2-ton trucks since the War, we developed the drive on one front and one rear axle because, we believe, that gave us the best and most uniform results.

The vehicles that enter the air service and the ones that are used by the field artillery both have intensive cross-country missions in time of peace, so we use their operations and their drill and training as a further laboratory of observation and test to see how they work. We hope, if the field artillery is successful in using these vehicles as prime movers, carrying heavy-artillery materiel and dragging the same materiel, we can use the same chassis for the air service and for the coast artillery and for all those services that require heavy duty.

For most of our military vehicles requiring cross-country operation, we find the type that we call the four-wheel four-wheel-drive—that is, driving on both front and rear axles—will meet most of our military requirements. Special requirements involving extra-heavy loads, even distribution of weight over a large-bearing tire-surface, and in vehicles required to pull trailers, six-wheel six-wheel-drive, and six-wheel four-wheel-drive types are required; but in all cross-country types we get the best results, that is, "maximum cross-country ability," where one of the driving axles is the front axle.

Simplification of Maintenance in War

J. E. HALE[13]:—Colonel Taylor commented repeatedly on the terrible confusion of making repairs and replacement on 200 different types of vehicles in the War. What is to be the future Army program as to procuring vehicles? Is there to be a standardized vehicle and, for instance, 2-ton chassis that will be all standardized and all designed to use only one chassis and thus simplify replacements? Or will the Army, in any future activities, simply go into the market and begin again to buy another 200 different types and so head right into the same difficulty? How will the specifications now being developed avoid all this confusion and the enormous number of different supply items?

LIEUTENANT-COLONEL TAYLOR:—The Army will not be able to avoid it unless the automotive industry foresees that trouble and helps. Our idea is that, in purchasing vehicles, we will purchase say 10 per cent additional units that pertain to those vehicles. For 100 trucks purchased at any one time, we would buy 10 additional engines, 10 axles, and so on. That is the general average, according to our estimates, of our requirements in unit replacement. We will also purchase, as we always have, the spare parts that are required for the maintenance of those units, rather than the vehicles. Unless there is a greater degree of interchangeability of units that pertain to 5-ton trucks, for instance, so that we can take out an engine manufactured by *A* and replace it by an engine manufactured by *B*, we will have the same trouble. But for the general characteristics of the engine required for a 5-ton truck, we believe that *A* and *B* and *C* can, through the Society perhaps, have some kind of standardization that will permit of a practical interchangeability. We absolutely need that interchangeability to avoid confusion.

Mr. Hale's question shows comprehension and appreciation of the Army's automotive problem and the critical situation it now faces in its vehicle-replacement program. I could not and cannot now—Oct. 12, 1931—answer his question directly, as I do not know what the attitude of the automotive industry will be toward standardization nor do I know what Congress will do. The Secretary of War necessarily must consider the views of both the industry and Congress, as well as the Army's needs. However, if vehicles for the Army are procured from the industry in accordance with the Quartermaster General's plans and principles of standardization, we will never again suffer the confusion, the extravagance in expenditure of funds for maintenance and the threat of general breakdown of motor transport, that marked our pioneer effort in the World War. If we do not standardize, these ills will be greatly aggravated in our next war due to the greatly increased motorization and mechanization that undoubtedly will be required.

The effect of decisions made in this regard, right now at the outset of our replacement program, upon the execution and final outcome of our next military operations, cannot be overestimated. The question is one of the most vital importance to our national defense.

[13] M.S.A.E.—Firestone Tire & Rubber Co., Akron, Ohio.

News of the Sections

Spark-Plugs Start Pittsburgh Season

EIGHTY-ONE dinner guests at the initial meeting of the Pittsburgh Section for the 1931-1932 season, held at the Fort Pitt Hotel on Oct. 6, listened to experts tell the story of spark-plugs and felt that the evening was a very profitable one.

B. H. Eaton, Chairman of the Section, said in his opening remarks that, by deciding upon one place for holding all its meetings, the Section had been able to reduce the cost of the meetings to the members while maintaining the high standard of the speakers and that out-of-town Section members can obtain, through any officer of the Section, special rates from the hotel while attending the meetings.

Plugs Developed for Severe Service

Otto C. Rhode, chief engineer of the Champion Spark Plug Co., talked on the Development, Design and Manufacture of Spark-Plugs, illustrating his address with lantern-slides. He stated among other facts that at present the so-called "porcelain" plugs predominate in the automotive field, a great development in their production having come with the introduction of Sillimanite as an insulating material toward the close of the World War. This material, which is no longer classed as porcelain, has great mechanical strength and electrical resistance and the ability to withstand severe heat shocks. Its development made possible changes in design that are among the reasons for the reliability of modern spark-plugs.

Introduction of superchargers in racing cars in 1923, continued Mr. Rhode, greatly increased the severity of spark-plug requirements and necessitated the development of that type of racing plug in which the insulator is seated below the outside gasket seat of the plug, thus securing a "cold" plug. However, as plugs were made to operate colder, they would stand correspondingly less slow-speed operation and had a greater tendency to foul. This led to the expression, "heat range." So now we say, "A hot plug for a cold engine; a cold plug for a hot engine."

Sumner Howard, service manager of the A. C. Spark Plug Co., told What Happens to Spark-Plugs, and emphasized, by means of lantern slides, the need for "selling a complete engine tune-up" instead of merely a set of new spark-plugs, and said that, instead of such vague terms as "easier cold-weather starting," "acceleration," and so forth, service men should emphasize fuel saving, which is more tangible and can be definitely proved. The difference in fuel consumption between an engine with worn-out spark-plugs and the same engine with new plugs will often be as much, he said, as 1½ to 2 pints per hour. Modern engines are much more severe in their spark-plug requirements than were former engines, because they run at higher speeds, have higher compressions and develop greater horsepower, so we are approaching racing-car tune-ups in the every-day maintenance of the modern automobile engine.

Flowmeter Shows Effect of Plugs and Carbureter Adjustments

R. C. Diehl, general service manager of the Marvel Carburetor Co., then demonstrated, by means of a flowmeter connected to a popular eight-cylinder car, the effect of new and old spark-plugs and of various carbureter adjustments on engine revolutions per minute and on fuel consumption. This flowmeter is essentially a back-pressure gage, being connected in the fuel line and adjusted so that a given rate of flow through a jet of constant size causes back pressure in a U-tube and shows the pressure on a calibrated scale.

Extremely low idling speeds require a rich mixture, said Mr. Diehl, which lowers the revolutions and wastes fuel throughout the speed range.

Several fleet owners asked pertinent questions, including, "What causes and what should be done about incrustations or barnacles on spark-plug insulators?" The answer was that these seem to be caused by something in the fuel and usually are found after using antiknock gasoline, but they cause no trouble unless a mechanic tries to scrape the barnacles off with a knife, which usually removes the glaze and ruins the insulator. A fluffy, light-gray deposit on the insulators tends to absorb carbon and cause trouble.

The principal discussers were Charles F. Kels, of the West Penn Power Co.; S. P. Marley, of the Mellon Institute of Industrial Research; and J. A. Harvey, of the Pittsburgh Motor Coach Co.

Syracuse Section Holds Aviation Meeting

AERONAUTICS held the attention of 115 members and guests of the Syracuse Section at the Oct. 5 meeting, which was held in cooperation with the Aeronautical Chamber of Commerce of America at Drumlin's following a members' dinner attended by about 100 and at which entertainment was provided.

The first address was made by A. E. Larsen, chief engineer of the Autogiro Co. of America, who told of the development and possibilities of the Autogiro and illustrated his talk with a two-reel sound film entitled, Wings of Tomorrow.

Major Thomas G. Lanphier, president of the Byrd Aircraft Co., next presented a paper on Engineering and its Relation to Aviation.

Among the discussers was George Crouse, who was a passenger on the transatlantic flights of the Graf Zeppelin and the Do-X and told of some of his experiences on those flights.

Professorial Meeting at Los Angeles

ENGINEERING professors were given the floor at the first meeting held by the Southern California Section this season. The meeting was held at the Elks' Temple, the evening of Oct. 2, with 75 members and guests present. Dinner was served to fortify the members against the onslaught, and an excellent orchestra and good colored quartet rendered entertainment. At a short business session, Charles F. Leinesch, manager of aviation for the Union Oil Co. of California, was declared elected Vice-Chairman of the Section for Aeronautics.

Following a short talk by Fred C. Patton, on the advantages afforded by membership in the Society, Ethelbert Favary spoke briefly of the value of education to men in the maintenance division of the automotive industry

Thomas Eyre, professor of mechanical engineering of the University of Southern California, talked on the relation of Engineering Colleges to Prospective Engineers. The ambition of colleges, he said, is to produce better men for the industries, give a man a fundamental background for engineering, teach him character building and develop the ability to work hard. He said that it is not well to specialize too much during a student's college course, as the demand in the business world is becoming less for definite specialists. Professor Eyre emphasized that engineers should have a good foundation in mathematics and physics, be able to speak good English and have the ability to speak well in public.

R. L. Daugherty, professor of mechanical engineering of the California Institute of Technology, talked generally on the education of engineering students, mentioned the difference of opinion on the subject of specialization of an engineering student along a different course of study and said that the trend seems to be away from specializing and toward giving the student a good foundation in a large number of subjects, but not to the extent that he is "Jack of all trades and master of none." Real specialization should come after graduation.

E. R. Hedrick, professor of mathematics of the University of California at Los Angeles, gave a very interesting talk on the University and some phases of standardization from an engineering standpoint. He spoke briefly on the Society for the Promotion of Engineering Education, of which he is an important member, as well as being a member of the Engineering Standards Association. He discussed methods of arriving at various standards as brought up by this association. Sizes of steel wire, shoes and other products, strange as it may seem, are arranged according to a mathematical formula of geometrical progression or a percentage of differences.

W. O. Kienholz, director of vocational education of the Los Angeles Board of Education, was introduced and spoke briefly, and Benjamin W. Johnson, assistant director of vocational education of the University of California at Los Angeles also was introduced.

Oregonians Consider Motoring as a Life and Health Hazard

THE RELATION of automobiles to health and accidents was discussed from various angles at the monthly meeting of the Oregon Section on the evening of Oct. 2 at the Multnomah Hotel in Portland. The members' dinner was attended by 56 and was accompanied by an entertainment provided by Fred Dundee, of the Dundee Automotive Service, and Vern Savage, superintendent of the City of Portland shops. Several more members dropped in after the dinner to hear the addresses.

Health and Its Relation to Safe Driving was the subject of a paper given by Dr. Albert Severeide, a local physician and surgeon, who explained in a lucid way how various diseases affect drivers' ability and why good health is essential to every motor-vehicle operator.

The injurious and often deadly effects of carbon monoxide and how they can be avoided were explained by Prof. S. H. Graf, of Oregon State College, in a paper on Carbon Monoxide and Oil Fumes.

A joint talk, with illustrations, on Accidents — Worse than War, was given by Kent Shoemaker, chief of the Operators' License Bureau of the State of Oregon, and Ray Conway, of the A.A.A. Oregon State Motor Association. Both speakers are well posted on facts and figures on accidents, their causes and ways in which they can be avoided.

J. E. Shelton, manager of the Oregon State Motor Association, was the guest of the evening and spoke briefly on the great need for safety in all traffic and travel. Other prominent discussers were Harlan W. Drake, superintendent of equipment for the Portland Gas & Coke Co.; James W. Cassell, editor of *Automotive News;* and Frank Allen, service superintendent of the International Harvester Co. in the Portland zone.

The entertainment, which was entitled Thrills, was devoted to safety, first, last and always.

Passenger-Car Development Reviewed and Forecast

ADVENT of rear-engine cars by 1933 was predicted by Herbert Chase, of New York City, at the monthly meeting of the New England Section at the Hotel Kenmore in Boston on the evening of Oct. 1. About 75 members and guests attended the meeting.

The title of Mr. Chase's paper was, Recent and Future Developments in Passenger-Cars, and the material in it was taken mainly from the paper presented by the author at the Summer Meeting of the Society last June, the major portion being devoted to rear-engine cars. The more important developments that have recently contributed to better cars were listed, various improvements adopted were discussed and free-wheeling was explained.

Various types of rear-engine cars built in Europe and one built in Detroit were illustrated with lantern slides, and Mr. Chase enumerated what he regards as the many advantages of placing the automobile powerplant in the rear.

In the course of the interesting discussion of such cars that followed, Mr. Chase said that three or four companies are experimenting with them now and many engineers are watching the developments.

Daytonans Inspect Publishing Plant

TWENTY-FIVE members of the Dayton Section took advantage of the opportunity afforded by the Sept. 29 meeting of the Section to become more familiar with the publishing business. The meeting was held at the plant of the McCall Publishing Co. in Dayton, where dinner was served to the visiting members and executives of the plant. Following the dinner, P. J. Dennerlien, of the McCall company, gave a short talk on Publishing and Printing a Magazine. Then the Section members were conducted through the plant to observe the processes of composing, imposing, printing and binding the McCall publications, which they found very interesting.

Philadelphia Cooperative Aeronautic Meeting

THE STATUS of aviation and the immediate future of the aeronautic industry in this Country were pictured and discussed at the Oct. 14 meeting of the Philadelphia Section, in which the Aeronautical Chamber of Commerce of America cooperated. Charles H. Colvin, president of the Pioneer Instrument Co., presented these phases for the Aeronautical Chamber, and Luther Harris, mechanical superintendent of the New York, Philadelphia, Washington Airways, known as the Ludington Lines, gave a paper entitled, Maintenance of Flying Equipment on Scheduled Operation.

The meeting was held the evening of Oct. 14 in the rooms of the Philadelphia Automobile Trade Association following a members' dinner attended by 44 members and supplemented with professional entertainment. W. Laurence LePage, Chairman of the Section, presided.

The subject of Mr. Colvin's address was Engineering and Its Relation to Aviation. The speaker pointed out that the progress made in aviation has been due largely to accomplishments in the engineering laboratory and that its future progress will also depend on engineering. The industry, however, cannot grow on the present limited commercial sales and therefore is dependent upon purchases by the Army and the Navy. The five-year program of military procurement is now nearing completion and a continuity of military policy, said Mr. Colvin, is essential to maintain the manufacturers in a position to meet the demands for equipment in event of a war involving our Country. Continued support by the Post Office Department of the air-transport system also is necessary.

Cleveland Section Considers Rubber-Mounted Engines

RUBBER-MOUNTED engines and so-called "floating power" as embodied in the Plymouth cars constituted the main topic discussed at the Oct. 12 meeting of the Cleveland Section, held at the Hotel Statler and attended by 170 members and guests. Sixty-nine were present at the dinner preceding the technical session, and good entertainment was provided, as usual.

Director Leyton E. Carter, of the Cleveland Foundation, gave a talk on the purposes of the Foundation, after which Newton F. Hadley, of the Plymouth Motors Corp., presented a paper on Floating Power, in which he described the vibration-absorbing suspension of the four-cylinder engine.

Among the discussers was R. W. Robinson, of the Firestone Tire & Rubber Co., who gave data on and specifications of the rubber used in the Plymouth cars; described destructive tests on rubber bonded to metal which showed that the rubber tears and the metal is distorted but no easy, clean break occurs between the metal and the rubber; and asserted that the life of the rubber engine-supports should equal the life of the car.

Other discussers were Webb Saffold, president of the Saffold Engineering Laboratories, and Ernest Schultheis, both of whom pronounced the Plymouth engine mounting a good job; and William Piwonka, engineer of the Cleveland Railway Co., who asked if idling vibration is unavoidable.

Baltimoreans Have an Ignition Symposium

TWO PAPERS on ignition subjects were presented at the Oct. 8 meeting of the Baltimore Section, held in the Emerson Hotel ballroom following a members' dinner accompanied by music. The technical session was attended by 146 members and guests.

The first paper, on Recent Developments in Spark-Plugs, was presented by Otto C. Rhode, chief engineer of the Champion Spark Plug Co. The second paper, on Ignition Systems, was given by John T. Fitzsimmons, engineer of the Delco-Remy Corp.

Principal discussers of the two subjects were Capt. S. G. Henry and Capt. L. L. Williams, of the United States Army; Joseph Bavett, of the Yellow Cab Co.; A. Preston Petre, of the American Hammered Ring Co.; and James H. O'Donnell, of Mack Trucks, Inc.

Some of the points discussed were the life expectancy of spark-plugs and batteries; causes and nature of failures;

how maximum service can be realized; how plugs are affected by pressure, cylinder-head design, fuel, lubricant, voltage and timing; battery versus magneto ignition; spark lag; electrical leaks; and trends and improvements in ignition equipment.

Indiana Section Holds a Big Aeronautic Meeting

SO KEEN was the anticipatory interest in the October joint meeting of the Indiana Section and the Aeronautical Chamber of Commerce of America that 60 members and guests were present at the dinner and 235 registered at the technical session in the Hotel Severin on the evening of Oct. 15.

The program was replete with attractions, including motion pictures of the building and first test flights of the new airship, Akron, the largest in the world, which has just been accepted by the Navy and is to be stationed for a time at Lakehurst, N. J. The pictures were shown by V. R. Jacobs, of the Goodyear Tire & Rubber Co., who gave an informal talk on the building, flights and mission of the ship. The picture and talk were accorded an enthusiastic reception.

Ralph Upson, aeronautic engineer who designed the Navy's experimental metalclad airship, ZMC-2, and who is now associated with the Stout Engineering Laboratories in the designing of the Stout Sky Car, gave a talk on The Quest of the Foolproof Airplane. He described briefly the engineering phases of the Sky Car and a new instrument that combines the functions of several conventional aircraft instruments. Details of the new instrument cannot yet be released for publication.

The third speaker was Charles F. Barndt, general manager of the Great Lakes Aircraft Corp., who delivered the message of the Aeronautical Chamber. His subject was, Engineering and Its Relation to Aviation.

At a brief business session of the Section a resolution was adopted, to be spread on the records of the Section, expressing deep sorrow of the members for the recent death of George T. Briggs, Past Secretary and Chairman of the Section, who had won the gratitude of the members by his years of devotion and invaluable leadership during many years, some of which were critical in the existence of the Section.

Kansas City Aero Meeting

OFFICERS and members of the Kansas City Section were keenly disappointed by the inability of Capt. Frank Hawks to address the meeting, as scheduled, on Oct. 9. Following the receipt of a last-minute telegram notifying the officers that he could not be present, the meeting was postponed to the evening of Oct. 14. John M. Miller, of the United States Medical Corps Reserve, a private owner of an Autogiro and now stationed at Kansas City, consented to act as a substitute speaker and gave an extemporaneous talk on the Autogiro. The meeting was held at the Fairfax Airport administration building, where dinner was served to about 50 members and guests.

Two prepared papers were presented, one on Aircraft Development in Recent Years, by Marion P. Crews, chief engineer of the American Eagle-Lincoln Aircraft Corp., and the other on Operation Costs, by Homer L. Bredouw, president of the Bredouw-Hilliard Aeronautic Corp.

Chairman James A. Edwards opened the meeting and introduced A. E. Gresham, who had charge of the aeronautic meeting under Hugh C. Garrett, Chairman of the Section's Program Committee.

Met. Section Hears about Zeppelin-Building Methods

A RAPID-FIRE talk crammed full of facts was delivered by V. R. Jacobs, of the Goodyear Tire & Rubber Co., on the subject, Building a Goodyear Zeppelin, at the Sept. 24 meeting of the Metropolitan Section. As usual, the meeting was held at the A.W.A. Clubhouse and 70 members and guests attended the dinner which preceded the technical session. About twice as many more came later to hear Mr. Jacobs. Entertainment during the dinner was provided by an orchestra.

Following the address, which was illustrated with lantern slides, the subject was discussed from the floor, the more prominent discussers being Carl B. Fritsche, president of the Aircraft Development Corp., and Lieut.-Commander J. C. Arnold, of the Naval Aircraft Station, Lakehurst, N. J.

Floating Power Described at Chicago

NEARLY 260 members and guests of the Chicago Section gathered on the evening of Oct. 13 at the Hotel Sherman to hear Newton F. Hadley, chief engineer of Plymouth Motors, give a paper on Floating Power, as exemplified in the Plymouth cars.

Attendance at the members' dinner preceding the technical session was 139, and entertainment was provided.

The keen interest in the subject was shown by the large number of persons who took part in the discussion, prominent among them being Stanwood W. Sparrow, of the research department of the Studebaker Corp.; James B. Fisher, chief engineer of the Waukesha Motor Co.; and A. W. Scarratt, chief engineer of the motor-truck and motor-coach division of the International Harvester Co.

Testing Airplane Performance

AIRPLANE-Performance Testing was the Chicago Section gathered on Paul W. Douglass, of the Stearman Aircraft Co., at the Oct. 8 meeting of the Wichita Section. The meeting was held as usual at the Green Parrot Inn, where dinner was served to 49 members. Half a dozen more came later to hear what Mr. Douglass had to say on the subject of the evening.

Great Welding Progress Predicted at Milwaukee

THE EXPLODING of many theories and the making of greater welding progress in the next five years than in the last decade were predicted at the October meeting of the Milwaukee Section by J. F. Lincoln, president of the Lincoln Electric Co., the speaker of the evening, whose subject was The Shielded Arc and Its Use in the Automotive Field.

The meeting was held Oct. 7 at the Milwaukee Athletic Club, following a $1-a-plate dinner and Whoodinee entertainment, and was attended by 93 members and guests. Chairman Henry L. Debbink, who presided, read extracts from current motor-vehicle laws and legislative bills to indicate the advisability of automotive engineers studying the action of legislators and the effects of measures that may be enacted. The names of members of the Governing Board of the Section for the current administrative year were announced.

Mr. Lincoln's paper was well illustrated with lantern slides of graphs including tensile-strength data on the parent metal and the fusion lines in electric welds. The speaker discussed the strength, hardness, elongation and resistance to corrosion of various combinations of parent metals, and emphasized particularly the low cost and assured results of the less porous welds obtained with the shielded arc-welding method. A few examples mentioned by the speaker of application of the method in which great economy has been effected are axle housings, wheel hubs, electric-starter frames, built-up gears, machine frames and jigs and fixtures.

According to Mr. Lincoln, the major obstacle to welding development today is the inertia of the designer in following in the footsteps of prior generations.

Braking and Brake Lining Discussed

DR. F. C. STANLEY, chief engineer of the Raybestos division of Raybestos-Manhattan, Inc., was the speaker at the October meeting of the Northern California Section, which was attended by 90 members and guests. The speaker gave a complete discussion of the braking conditions on motor-trucks and trailers and gave information on the coefficient of friction of brake linings. His talk was illustrated with slides of brake-testing machines used at the Bureau of Standards and in the industry. The point most emphasized by Dr. Stanley in connection with braking efficiency was the importance of the care exercised by the driver. Tests of various brake-drums were shown and the general swing to cast-iron drums was indicated. Many of the listeners took part in the discussion on the subject.

The Section's next meeting is to be held at Stanford University on Nov. 12, when the members will be conducted on a tour of the laboratories and Prof. A. B. Domonoske will be in charge of the meeting.

Thomas Alva Edison

TOGETHER with all of the world, automotive engineers deeply deplore the ending of the life of Americas most world-famous inventor, whose innumerable achievements have given more comfort and enjoyment to a greater number of human beings than those of any other man in history. The most notable characteristic of the untiring efforts of Thomas A. Edison was the fact that his inventive and experimental genius was directed in the main toward the development of things that closely touched the daily lives of the masses of the people. To realize this, it is necessary only to consider his pioneer work in the invention of the incandescent electric lamp, the typewriter, the phonograph, the motion-picture camera and his numerous patents relating to electric street-cars and locomotives. Although Mr. Edison did not accumulate a great fortune as a result of his indefatigable application to his laboratory work and inventive effort, the industries that have been built upon the foundations he laid are estimated to represent a value amounting roughly to $20,000,000,000.

Products developed upon the principles of Mr. Edison's inventions have penetrated to all parts of every country of the globe, and there is hardly a soul in the world but owes a debt of gratitude to this great man, who was beloved not alone for his practical contributions to the advance of civilization, but also for his simplicity, his modesty, his kindliness and courtesy to all who came into contact with him.

Mr. Edison may be said to have inaugurated the age of practical application of electricity, not alone to lighting, but to power generation and distribution. Every day and everywhere about us we have the evidence of how men's lives have been made easier, brighter and more comfortable and enjoyable because of the half century of devotion of this one man's life to fundamental study of problems relating to essentially practical developments of a revolutionary character. Although few of the great inventor's patents related directly to the automotive industries, many of them had an indirect bearing on them, led to specific applications to motor-vehicles and aircraft and facilitated the work of automotive engineers and research men everywhere.

The incandescent electric lamp was, of course, the precursor of all such lamps and related devices that have such a wide application in research instruments and in production processes, as well as in factory, office and home illumination. Many meetings of the Society are made more informative and interesting by means of motion pictures, which are the outgrowth of the kinetograph camera patented by Mr. Edison in 1891. Even the typewriters that are such an aid to engineers in their work trace back to the Edison patent of 1871, which was the outcome of work done by Mr. Edison with Mr. Sholes on the first working model that eventually was developed into the Remington typewriter.

Many of the more than 1200 patents granted to Mr. Edison from 1869 to the present time relate to improvements in the electrical field. The nickel-alkali storage battery has been used to some extent directly in motor-vehicles, in which the famous inventor always was much interested. Some years ago he worked with H. E. Dey in the development of an electric vehicle in which the field and armature were built into the rear axle and rotated in opposite directions. The effect, discovered by Mr. Edison, of an independent wire or plate placed between the legs of the filament of an incandescent lamp in controlling the flow of current is the basic principle of the radio tube, which has found its application in aircraft. In 1912 the inventor was granted a patent on a starting and current-supplying system for automobiles, and in 1915 he installed benzol plants in which various by-products were produced from coal. Within the last year, Mr. Edison displayed keen interest in the Autogiro, which he saw in flight at the Newark Airport. He had given much study to rubber and for a number of years recently had been experimenting in Florida with the production of rubber from goldenrod.

Mr. Edison had been a Member of the Society for 20 years, having been elected in May, 1911. He was born at Milan, Ohio, in 1847. The history of his life and lists of his inventions were published in detail in leading newspapers throughout the Country immediately following the news of his death on Sunday, Oct. 18.

THOMAS ALVA EDISON

Joseph Bijur

WHEN the superintendent of the Bijur Lubricating Corp. was going through its Long Island City factory Monday morning, Oct. 19, he discovered the bodies of Joseph Bijur, the president and general manager, and Mrs. Bijur. Thus ends the services of a man who has been a member of the Society since 1910 and was one of the pioneers at several stages of the automotive industry, particularly in the application of electric starting and lighting to automobiles and electric starters to airplane engines. He also was one of the real pioneers in advocating standardization as applied to automobiles.

Born in New York City in 1874, Mr. Bijur was educated in private schools and Columbia University, receiving degrees of A.B. and E.E. His first contact with the automotive industry was in 1899, when he was engaged in the construction and testing of Siemens & Halske motors for electric vehicles in Chicago. In 1904 he organized the General Storage Battery Co., which made batteries for vehicle propulsion and for

ignition in Boonton, N. J. He was president of this organization until it became the Westinghouse Storage Battery Co., in 1908, after which he was retained as consulting engineer by that company.

When Packard cars were first equipped with an electric starting and lighting system, trouble was encountered with regulation, and Mr. Bijur developed a reversible voltage regulator which was applied to the generator. He organized the Bijur Motor Appliance Co. in 1910 and manufactured in Hoboken the starting motors and generators that were used for a number of years thereafter on Packard and other cars.

Among the more than 200 patents issued to Mr. Bijur was the basic patent for an automatic starter gear with a screw shift. Starters for aviation engines also were developed at the Bijur plant. The business of the Bijur Motor Appliance Co. was acquired by the General Electric Co. in 1919.

The central chassis-lubricating system is another important motor-car accessory which owes much of its early development and present success to Mr. Bijur, who organized the Bijur Lubricating Corp. in 1923 and again secured Packard as the first customer of his enterprise.

Mr. Bijur has been a familiar figure at Annual and Semi-Annual Meetings of the Society and at meetings of the Metropolitan Section. He delivered a comprehensive paper on starting and lighting systems, which was printed in Part 1, vol. 11 of THE TRANSACTIONS (1916), and another on The Central-Point Chassis-Lubricating System, which was printed in THE JOURNAL in March, 1925. Mr. Bijur served on the Standards Committee for several years between 1914 and 1920, and was a member of the Finance Committee of the Society from 1927 to 1930.

J. Richard Francis

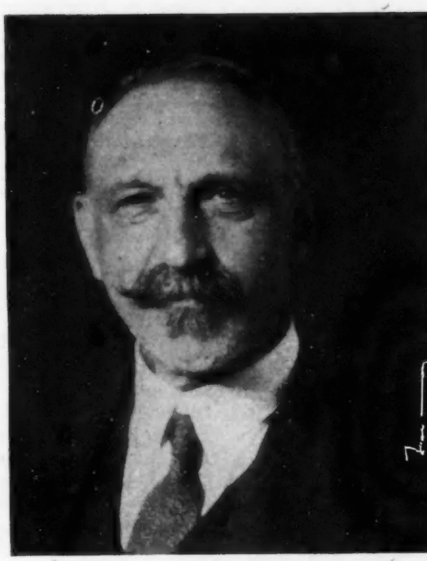
IN THE RECENT DEATH of J. R. Francis, president and general manager of the Marvel Carburetor Co., of Flint, Mich., the industry lost a man who had been engaged in experimental work with the manufacture of carbureters for the last 23 years and who had had a long experience before that period as a chemist. He was admitted to Member grade in the Society in 1916, at which time he was general manager of the Marvel company, and in 1927 he was elected president of the company as well as general manager.

Mr. Francis was born at Fountaintown, Ind., in 1870, and in 1893 received the degree of Graduate in Pharmacy from Purdue University. For two years following his graduation he served as first assistant to the State chemist of Indiana and then organized a company to take over the analytical laboratory of the State chemist. From 1903 to 1911 Mr. Francis was chemist of the Big Four Railroad, for which he was engaged for eight years in charge of analytical chemical work in connection with carbureters. His next and last connection was with the Marvel Carburetor Co.

Paul M. Boyd

AN AIRPLANE accident in Buffalo last September resulted in the untimely death of Paul M. Boyd, head of the flight-test section and chief powerplant design engineer of the Curtiss Aeroplane & Motor Co. of Garden City, N. Y.

Mr. Boyd became a Junior Member of the Society in February, 1926, and was transferred to Member Grade a year ago. He was born at St. Paul, Minn., in September, 1900, and received his engineering education in the College of Engineering of the University of Minnesota, from which he received the degree of Bachelor of Science in 1924, and in the aeronautical engineer-



JOSEPH BIJUR

ing department of the Massachusetts Institute of Technology in 1924 and 1925.

From 1922 to 1924, Mr. Boyd was a pilot and mechanic for the Curtiss Northwest Airplane Co., of Minneapolis. The following year he went to Garden City, Long Island, as a draftsman and production engineer with the Curtiss Aeroplane & Motor Co., overseeing and following up assembly work on the factory floor. In 1926 he was made project engineer, in 1929 was promoted to head of the flight-test section, and in 1930 was given supervision of powerplant installation, engineering and assembling.

Although only 31 years of age, Mr. Boyd was highly regarded by his superiors in the Curtiss company as an expert and authority in aeronautic work.

George Theodorus Briggs

FOLLOWING protracted ill health that became serious in August, George T. Briggs, an Associate Member of the Society since 1911 and sales manager of the Wheeler-Schebler Carburetor Co., of Indianapolis, until he retired from active work in 1927, passed away on Oct. 3 at St. Vincent's Hospital in Indianapolis.

Mr. Briggs was born at Brandon, Vt., in 1876 and was for a time engaged in railroad work with the Quincy, Manchester & Sargent Co. before entering the automobile industry in 1903, at which time it was in its infancy. Throughout nearly quarter of a century he devoted his efforts to sales to automobile manufacturers, having been sales manager of the Factory Sales Corp., of Chicago, before going to Indianapolis as sales manager of the Wheeler-Schebler Carburetor Co. At one time he was president of the Motorcycle & Allied Trades Association, of Chicago.

During his 20 years' membership in the Society, Mr. Briggs was very active in its work. He was Chairman of the Mid-West (now the Chicago) Section in 1920; Secretary of the Indiana Section in 1923 and 1924; Chairman in 1925 and Vice-Chairman in 1926; a member of the Membership Committee of the Society in 1924; and a member of the Sections Committee during 1925, 1926 and 1927.

Hamilton Morton Stephens

WITH THE DEATH of H. Morton Stephens, western sales manager of the Oakland Motor Car Co., in Detroit on Sept. 23, the industry lost a member of unusual capacity and great versatility as well as one of universal popularity.

Before his entry into the automobile industry, Mr. Stephens had been engaged in important civil engineering work for 16 years. His first contact with the automobile industry came as resident engineer and construction manager for E. I. du Pont de Nemours & Co. from 1919 to 1921, during which time he supervised the construction of a score of General Motors Corp. and an equal number of du Pont plants in the United States and Canada. He was then appointed district manager of sales and service for the eastern United States and Canada for the Cadillac Motor Car Co. In 1924 he was made general manager of the Chicago branch of the Cadillac company, and in 1926 was appointed general sales manager at the Detroit plant, a position he retained until, in 1930, he was made western sales manager for Oakland.

Born at Middletown, Del., in 1883, Mr. Stephens attended the Philadelphia High School and studied civil engineering at Delaware College. After being graduated, he was successively assistant chief engineer of the National Railway Co. of Haiti; resident engineer for the Winston-Salem Southbound Railway Co.; assistant engineer in charge of constructing municipal works in North Carolina; superintendent of the Purcell Construction Co., in charge of railroad construction in Pennsylvania; superintendent of construction for the T. A. Gillespie Co., in charge of a section of the New York State barge canal; superintendent for H. S. Kerbaugh, Inc., and the Empire Engineering Corp.; and then construction manager for the du Pont company.

Mr. Stephens became an Associate Member of the Society in 1928 and was also a member of the American Society of Civil Engineers, the Detroit Athletic Club and other Detroit clubs.

Personal Notes of the Members

Glover To Be President of Consolidation

Announcement has been made that on Jan. 1 next the Timken-Detroit Co. and the Silent Automatic Corp. will be consolidated under the name Timken Silent Automatic Co. and that Fred Glover, president of the Timken-Detroit Axle Co., the parent organization, will also serve as president of the new combination. All activities in the manufacture of oil-burning heating equipment will be conducted after this year at the Clark Avenue plant of the Timken-Detroit Axle Co.

Wyman-Gordon Personnel Changes

At a recent stockholders' meeting of the Wyman-Gordon Co., of Worcester, Mass., George F. Fuller, former president, was made chairman of the board of directors and Harry G. Stoddard, a former vice-president, was elected president. F. A. Ingalls was reelected vice-president. Other members of the Society in the company received executive appointments as follows:

S. M. Havens, formerly works manager at the Ingalls-Sheppard division in Harvey, Ill., is now general manager of that division; J. D. Sutherland, formerly general sales agent at Harvey, is now assistant to the president; H. F. Wood, who was assistant works manager of the Ingalls-Sheppard division, was made works manager; J. H. Nelson was reappointed works manager of the Worcester, Mass., division; and F. E. Wellington, formerly manager of the aviation division in Worcester, was appointed district sales manager of the Worcester division.

Charles W. Adams has assumed new duties as sales engineer for the Speer Carbon Co., of St. Marys, Pa., and is located at Saginaw, Mich.

Gould Allen, formerly vice-president in charge of sales for the Chassis Lubricating Co., Inc., of Detroit, is now representative in that city of the Buda Co., of Harvey, Ill.

Arthur C. Bates has resigned his position as research assistant at the engine experiment station at Purdue University, West Lafayette, Ind., to become instructor in mechanical engineering at the Towne Scientific School, University of Pennsylvania, in Philadelphia.

Charles Beck has been elected president of the Beck Knob Corp., of Chicago. His former post was that of president with the Beck Frost Ohio Co., of Toledo.

Rex B. Beisel, having resigned as vice-president and chief engineer of the Spartan Aircraft Co., of Tulsa, Okla., is now associated with the Chance Vought Corp., of East Hartford, Conn.

Radford J. Berky, formerly a draftsman for the Chance Vought Corp., of East Hartford, Conn., now holds a similar position with the Curtiss Aeroplane & Motor Co., of Buffalo.

M. P. Brooks, having resigned as superintendent of equipment in the equipment department, Division of Highways, State of California, is now serving as superintendent of equipment and garages for the Pacific Freight Lines, of Los Angeles.

John W. Brown has been elected vice-president of the Corcoran-Brown Lamp Co., of Cincinnati. In the past he was president of the John W. Brown Mfg. Co., of Columbus, Ohio.

Clayton R. Burt, president and general manager of the Pratt & Whitney Co., of Hartford, Conn., has announced the purchase by his company of the business and plant of the Keller Mechanical Engineering Corp., of Brooklyn, N. Y., which will be moved to the plant of the Pratt & Whitney Co., in Hartford.

Madison Mott Cannon, who was a student at the Massachusetts Institute of Technology, has been appointed assistant in the Institute's department of mechanical engineering in Cambridge, Mass.

A. Ludlow Clayden, research engineer for the Sun Oil Co., of Philadelphia, has been transferred to the company's Detroit branch.

H. S. Cocklin, formerly chief engineer of the Dornier Co. of America, of New York City, is now affiliated with the General Aviation Mfg. Corp., of Dundalk, Md.

W. Chapin Condit, until recently research engineer for the Sun Oil Co., at Marcus Hook, Pa., has been transferred to the company's sales department in New York City.

Jerome M. Cook has assumed new duties as assistant superintendent of the experimental department of the Oakland Motor Car Co., of Pontiac, Mich. He was research engineer for the Hercules Motor Corp., of Canton, Ohio.

Robert Y. Copland, formerly stationed at Montreal as director of planning and engineering for the Dominion Rubber Co., Ltd., has been transferred to the company's plant in Kitchener, Ont.

Richard Coulson, a Foreign Member of the Society and a specialist in front-end drives, who has been closely associated with the development of the compound roller chain now used for this work in Europe, has joined the Alfred Appleby Chain Co., Ltd., of Birmingham, England, and will have charge of all matters relating to automobile-chain applications.

Charles H. Crockett, who was engaged in special research, design and patent engineering work for the Thos. J. Corcoran Lamp Co., of Cincinnati, has organized the firm of C. W. Crockett & Sons, of Troy, N. Y., with his father, C. W. Crockett, who is professor of mathematics and astronomy at the Rensselaer Polytechnic Institute. They are developing a spring-suspension system for a light car and also carry on some head-lamp work.

Roscoe Leroy DeSpain has been promoted from the position of automotive district superintendent to that of chief inspector for the Shell Petroleum Corp., of St. Louis.

Leighton Dunning now holds the post of purchasing agent for the Kellett Aircraft Corp., of Philadelphia. His preceding position was that of manager of the shock-absorber division of Thompson Products, Inc., in Detroit.

Having severed his connection with the Fisher Body Corp., of Detroit, as die-designing engineer and checker, **Henry J. Edling** recently associated himself with the Peninsular Engineering Co., Inc., also of Detroit, with which he holds the position of president.

George B. Fuller is now filling the post of aeronautic engineer at the Hancock Foundation College of Aeronautics in Santa Maria, Calif. He formerly held a similar position with the Walker M. Murphy Co., of Pasadena, Calif.

Lewis H. Gates, having given up his position of assistant superintendent with the Atterbury Motor Car Co., of Buffalo, is now connected with the Pierce-Arrow Motor Car Co., of the same city.

Eric Geertz, having given up the position of mechanical engineer with the Link Belt Co., of Indianapolis, was recently appointed chief engineer of the Barber Greene Co., of Aurora, Ill.

Having left the tractor department of the Rock Island Plow Co., of Rock Island, Ill., **Albert H. Gilbert** is working independently as a tractor-designing engineer.

Edwin H. Godfrey has relinquished the position of chief engineer of the Glenn L. Martin Motor Co., of Baltimore. His present address is 209 South Marion Avenue, Wenonah, N. J.

John J. Grabfield, formerly test engineer for the Hudson Motor Car Co., of Detroit, has organized a firm of his own under the name John J. Grabfield & Associates, of Detroit, to engage in automotive and aeronautic engineering. He is the senior associate.

George H. Hannum, formerly president of the Hannum Mfg. Co., of Milwaukee, is now general manager of the Heintz Mfg. Co., of Philadelphia.

Mark Harris, who was manufacturing research engineer for the H. H. Franklin Mfg. Co. of Syracuse, N. Y., has been appointed chief engineer of the Gabriel Co., of Cleveland, to which he brings his experience of more than 20 years in automotive engineering and sales work.

(*Continued on p.* 32)

Applicants Qualified

The following applicants have qualified for admission to the Society between Sept. 10 and Oct. 10, 1931. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff.) Affiliate; (S M) Service Member; (F M) Foreign Member.

Armstrong, J. H. (A) president, C. A. S. Engineering Co., 5-139 General Motors Building, *Detroit*.

Baxter, H. X. (A) vice-president, J. H. Baxter & Co. and Horace X. Baxter S. S. Co., 702 American National Bank Building, *San Francisco*.

Boots, Edmund R. (M) American Gas Accumulator Co., 420 Lexington Avenue, Room 2713, *New York City*.

Bowers, W. T. (M) service manager, automobile maintenance, William Schluderberg-T. J. Kurdle Co., Baltimore; (mail) 3 Paradise Park, *Sparrows Point, Md.*

Boyle, Charles Edwin (A) field representative, western Canada, Ethyl Gasoline Corp., New York City; (mail) 5615 11th Avenue, N. E., *Seattle, Wash.*

Coates, John (A) General Motors New Zealand, Ltd., *Petone, New Zealand*.

Colin, Philip Gordon (M) supervisor, research division, Tide Water Oil Co., *Bayonne, N. J.*

Cooper, Cyril (M) president, general manager, Windsor-Chatham-London Coach Lines, Ltd., 486 Ouellette Avenue, *Windsor, Ontario, Canada*.

Freeman, Robert G. (M) instructor, General Motors Institute of Technology, *Flint, Mich.;* (mail) 845 East Eighth Street.

Goetz, Martin G. (A) division lubricating engineer, Pennzoil Co., *Detroit;* (mail) 80 Seward Avenue.

Halford, Frank Bernard (F M) designer of aeronautic and automobile engines, 8 and 9, Golden Square, *London, W. 1, England*.

Helm, Logan B. (A) superintendent, Standard Oil Co. Refinery No. 2, Midland Bank Building, *Cleveland*.

Hoover, Wm. P. (J) draftsman, price estimator, American Bearing Corp., *Indianapolis;* (mail) 1210 North Pershing Avenue.

Houdin, Charles (F M) general manager of production, Societe Anonyme Andre Citroen, 143 Quai de Tavel, *Paris, France*.

Knohl, Karl (J) designer, 3117 North Kilbourn, *Chicago*.

Kohler, J. F. (A) shop superintendent, Collins Brothers Co., Box 116, R. F. D. No. 1, Milwaukee Branch, *Portland, Ore.*

Kono, Yukio (A) owner, Kono Auto Repair, 407 12th Avenue, *Seattle, Wash.*

Leland, Douglas G. (J) aviation machinist's mate, United States Navy; (mail) U. S. S. Lexington, care of Postmaster, *New York City*.

Leonard, Simpson C., Jr. (M) secretary, treasurer, Michigan Leather Packing Co., Inc., 548 East Fort Street, *Detroit*.

Mann, Robert Ward (A) manager, Isaacson Iron Works, 320 Oregon Street, *Portland, Ore.*

Maw, Frederick Arthur L. (F M) chief engineer, Vacuum Oil Co. Proprietary, Ltd., 90 William Street, *Melbourne, Victoria, Australia*.

Paxton, Sherman L. (A) garage superintendent, Standard Oil Co. of New Jersey, New York City; (mail) Standard Oil Co. of New Jersey, *Charlotte, N. C.*

Pile, J. Howard (M) editor in charge of research, investigation and production, Chek-Chart Corp., 624 South Michigan Avenue, *Chicago*.

Rice, Clarence W. (A) sales manager, El Dorado Refining Co., El Dorado National Bank Building, *El Dorado, Kan.*

Sanwald, G. Leonard (J) junior engineer, aeronautic engine laboratory, Naval Aircraft Factory, Philadelphia Navy Yard, *Philadelphia*.

Schultz, Eugene Charles (J) engineer, rolling stock and shops department, New Orleans Public Service, Inc., *New Orleans;* (mail) 225 Harrison Avenue.

Searle, Dudley F. (A) sole owner, Searle Air Brake Co., 1632 East 12th St., *Oakland, Calif.*

Stradling, Danna J. (A) motor-vehicle inspector, Standard Oil Co. of New Jersey, *Richmond, Va.;* (mail) 203 Park Avenue.

Thayer, Byron C. (J) draftsman, Curtiss-Wright Airplane Co., *Wichita, Kan.;* (mail) 556 South Grove Street.

Whitehouse, Irving (M) engineering representative, Lord Mfg. Co., *Erie, Pa.;* (mail) 4610 Homeland Boulevard.

Work, Boyd H. (A) sales engineer, Carborundum Co., *Niagara Falls, N. Y.*

Wright, George W. (A) superintendent, garage department, Toronto Transportation Commission, 35 Yonge Street, *Toronto 2, Ontario, Canada*.

Applicants for Membership

The applications for membership received between Sept. 16 and Oct. 15, 1931, are listed below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

Baldridge, Dale D., manager, service and maintenance department, Jensen Brothers Garage, *Gustine, Calif.*

Barton, Charles Allen, general superintendent, rolling stock and shops department, Rio de Janeiro Tramway Light & Power Co., Ltd., *Rio de Janeiro, Brazil, S. A.*

Bates, Arthur C., instructor in mechanical engineering, University of Pennsylvania, *Philadelphia*.

Bergstrom, S. E., district sales manager, Cincinnati Milling Machine Co., *Cincinnati*.

Bottrell, George William, works manager, Canadian Hanson Van Winkle Co., Ltd., *Toronto, Ont., Canada*.

Case, Richard Y., chief draftsman, L. H. Gilmer Co., *Tacony, Philadelphia*.

Casiraghi, Giovanni, structural engineer, Waco Aircraft Co., *Troy, Ohio*.

Conrow, Jab Atkinson, inspection, Glenn L. Martin Co., *Baltimore*.

Davine, J. L., sales representative, Ethyl Gasoline Corp., *Boston*.

Faller, Raymond R., automotive engineer, Ethyl Gasoline Corp., *New York City*.

Forslund, Olof Ruben, layout man, Hudson Motor Car Co., *Detroit*.

Glen, John G., manager, hard-rubber division, United States Rubber Co., *Providence, R. I.*

Gross, Russell R., factory manager, Firestone Tire & Rubber Co., *Akron, Ohio*.

Gurton, William S., managing director, Dominion Truck Equipment Co., Ltd., *Kitchener, Ont., Canada*.

Habach, George F., computer, Worthington Pump & Machinery Corp., *Harrison, N. J.*

Hayes, Matthew Thomas, special equipment engineer, General Motors Truck & Coach Co. of Canada, Ltd., *Walkerville, Ont., Canada*.

Hazlitt, Cecil John, service manager, Larke, Neave & Carter, Ltd., *Sydney, Australia*.

Hervey, J. P., research student, Harvard University, *Cambridge, Mass.*

Hill, James R., Major, Quartermaster Corps, United States Army, *City of Washington*.

Howard, Nelson, 2nd, 65 Robin Street, *West Roxbury, Mass.*

Johnson, Joseph Blaine, director, chief engineer, assistant general manager, Bryant Chucking Grinder Co., *Springfield, Vt.*

Jones, Arthur Aubrey, works manager and chief engineer, Metropolitan Omnibus & Transport Co., Ltd., *Sydney, Australia*.

Kaap, Lawrence Edward, student aeronautical engineer, University of Wisconsin, *Madison, Wis.*

Kissling, F. R., vice-president, general manager, Wheeler Metal Products Corp., *Cleveland*.

Kohler, Henry L., Jr., instructor, University of Michigan, *Ann Arbor, Mich.*

Ladd, Harvey D., service manager, Kenworth Motor Truck Co., *Seattle, Wash.*

Leland, Willard E., national user salesman, International Harvester Co. of America, *Baltimore*.

Maverick, George M., director, research laboratories, Standard Oil Development Co., *Elizabeth, N. J.*

Meyer, John, patent draftsman and detailer, Wright Aeronautical Corp., *Paterson, N. J.*

Mondrush, Gustave M., checker and designer, Heintz Mfg. Co., *Philadelphia*.

Needies, I. G., sales manager, tire division, Canadian Goodrich Co., Ltd., *Kitchener, Ont., Canada*.

Nelson, Henry B., chief inspector, Kenworth Motor Truck Corp., *Seattle, Wash.*

Nordquist, Harry E., branch manager, Laher Auto Spring Co., *Seattle, Wash.*

Pangborn, Edward L., chief draftsman, in charge of body detailers, Ford Motor Co., *Dearborn, Mich.*

Puls, Edwin E., lubrication engineer, Cities Service Oil Co. (Michigan), *Adrian, Mich.*

Rasmussen, Richard E., superintendent, Chevrolet Motor Co., *Detroit*.

Riley, Robert Sanford, experimental test engineer, Pratt & Whitney Aircraft Co., *East Hartford, Conn.*

Robbins, Joseph E., manager, transportation and mechanical departments, Paramount Publix Corp., *Los Angeles*.

Roestel, John F., 2676 North First Street, *Milwaukee*.

Rosenzweig, Isidore, 234 East Third Street, *New York City*.

Scully, Frank P., president, Thermo Hydraulic Shock Absorber Co., *Cambridge, Mass.*

Sperling, Milton, automotive engineer, Richfield Oil Co. of California, *Los Angeles*.

Way, Gilbert, experimental engineering department, Chrysler Corp., *Detroit*.

West, Harry T., Jr., sub-foreman, Boeing Airplane Co., *Seattle, Wash.*

Williams, John Sheppard, rodman, South Carolina State Highway Department, *Augusta, Ga.*

Windle, William John, Jr., vice-president, W. & B. Auto & Repair Co., *Irvington, N. J.*

Wood, William Lewis, manager, motor-vehicle division, West Chicago Park Commission, *Chicago*.

Voshall, Leroy Brodbeck, mechanical engineer, The Texas Co., *Beacon, N. Y.*

Notes and Reviews

AIRCRAFT

Airship Model Tests in the Variable-Density Wind-Tunnel. By Ira H. Abbott. Report No. 394. Published by the National Advisory Committee for Aeronautics, City of Washington, 1931; 24 pp., illustrated. Price, 20 cents. [A-1]

An investigation of the aerodynamic characteristics of airship models was made in the variable-density wind-tunnel of the National Advisory Committee for Aeronautics. Eight Goodyear-Zeppelin airship models, supplied by the Bureau of Aeronautics of the Navy Department, were tested in the original closed-throat tunnel. After the tunnel was rebuilt with an open throat, a new model was tested, and one of the Goodyear-Zeppelin models was retested. These tests were made at tank pressures varying from 1 to 20 atmospheres, and the extreme range of Reynolds number was about 1,000,000 to 40,000,000. The lift, drag and moment coefficients of the models were ascertained and the effects upon these coefficients of pitch, fineness ratio, scale, surface texture, initial degree of air-stream turbulence, and the effects of the addition of fins and cars were investigated. The resulting curves are included.

The results show that the addition of fins and car to the bare hull of a model causes an increase in lift at positive angles of pitch and causes an additional drag which increases with the pitch. Little change in drag coefficient was found between a fineness ratio of about five and seven. The effect of surface roughness on drag was found to be very large. The drag coefficient and the apparent effect of scale depend upon the initial degree of air-stream turbulence. The results indicate that much can be done to determine the drag of airships from evaluations of the pressure and skin-frictional drag on models tested at large Reynolds numbers.

Tests of N.A.C.A. Airfoils in the Variable-Density Wind-Tunnel. Series 43 and 63. By Eastman N. Jacobs and Robert M. Pinkerton. Technical Note No. 391; 32 pp., 12 figs. [A-1]

Tests of N.A.C.A. Airfoils in the Variable-Density Wind-Tunnel. Series 45 and 65. By Eastman N. Jacobs and Robert M. Pinkerton. Technical Note No. 392; 30 pp., 11 figs. [A-1]

The foregoing two Technical Notes were published during September, 1931, by the National Advisory Committee for Aeronautics, City of Washington.

The Development, Design and Construction of Gliders and Sailplanes. By A. Lippisch. Reprinted from *The Journal of the Royal Aeronautical Society*, July, 1931. Technical Memorandum No. 637; 38 pp., 46 figs. [A-1]

The Dangerous Sideslip of a Stalled Airplane and Its Prevention. By Richard Fuchs and Welhelm Schmidt. Translated from *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, Vol. 22, No. 13, July 14, 1931; Verlag von R. Oldenbourg, München und Berlin. Technical Memorandum No. 638; 16 pp., 19 figs. [A-1]

These items, which are prepared by the Research Department, give brief descriptions of technical books and articles on automotive subjects. As a rule, no attempt is made to give an exhaustive review, the purpose being to indicate what of special interest to the automotive industry has been published.

The letters and numbers in brackets following the titles classify the articles into the following divisions and subdivisions: *Divisions*—A, Aircraft; B, Body; C, Chassis Parts; D, Education; E, Engines; F, Highways; G, Material; H, Miscellaneous; I, Motorboat; J, Motorcoach; K, Motor-Truck; L, Passenger Car; M, Tractor. *Subdivisions*—1, Design and Research; 2, Maintenance and Service; 3. Miscellaneous; 4, Operation; 5, Production; 6, Sales.

On Floats and Float Tests. By Friedrich Seewald. Translated from *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, Vol. 22, No. 9, May 15, 1931; Verlag von R. Oldenbourg, München und Berlin. Technical Memorandum No. 639; 25 pp., 10 figs. [A-1]

The New Charlestop Remote Brake Transmission and Control. By Pierre Leglise. Translated from *L'Aeronautique*, No. 146, July, 1931. Technical Memorandum No. 640; 3 pp., 12 figs. [A-1]

The foregoing four Technical Memoranda were issued during September and October, 1931, by the National Advisory Committee for Aeronautics, City of Washington.

A Study of Slots, Rings and Boundary-Layer Control by Blowing. By H. C. H. Tounend. Published by *The Journal of the Royal Aeronautical Society*, August, 1931, p. 711. [A-1]

In this paper a study has been made of certain cases of air-flow in which various means are employed to control the behavior of the air so as to prevent breakdown in the flow and the resulting turbulence. The study is mainly an attempt to analyze the evidence which exists on such phenomena as slots, rings and boundary-layer control by means of blowing through backwardly directed slots in the surface, and to determine, if possible, the extent to which their apparent similarity corresponds, if at all, to an identity of physical principle.

Some of the published results of a great deal of experimental work that has been done at various times on such devices are discussed and an attempt made to correlate them. In addition, some further experiments have been made to fill up gaps in the available data or to extend their scope. They include other examples of control of air-flow at sharp corners (Part I); some of the cases considered differ widely from others, but all exhibit the reduction in eddying which results from assisting air to negotiate sharp corners or bluff obstacles with the least disturbance possible.

A study of these cases is made in Part II, in which their points of similarity and difference are discussed and conclusions are drawn with regard to the essential features of each.

The Metal-Clad Airship. By Carl B. Fritsche. Published in *The Journal of the Royal Aeronautical Society*, September, 1931, p. 818. [A-1]

Brief historical notes on the development of the airship serve as introduction to a complete description of the first successful metalclad airship, the ZMC-2. The author follows this description with a thorough analysis of the problems of design, construction and operation of this type of aircraft.

In his summary of the advantages of the metalclad system of rigid-airship construction, Mr. Fritsche enumerates the following: simplicity of design and construction; no indeterminate hull stresses; fireproofness; durability of plating; superior gas-tightness; ease of maintenance and inspection of hull; rigidity of hull shape at high speeds; greater gas volume for the same air displacement; no moisture absorption; no loss of speed due to flapping fabric; superiority at high speed; no deterioration under tropical sunshine; ability to increase strength by higher pressure, yet rigid enough to fly with atmospheric pressure; wider range of inside pressure variation; perfect electric bonding of all structural parts; economy in operation; weatherproof qualities; commercial safety: and adaptability to outside mooring at terminals.

The author points out that two of these advantages are of paramount importance to commercial operation: (*a*) inherent safety and (*b*) ability to operate continuously at high speeds in the region of 100 m.p.h. or more, both of which result from its improved principles of design, the choice of materials, integrity of the hull structure and the method of operation.

Research Work of the D.V.L. By Wilhelm Hoff. Published in *The Journal of the Royal Aeronautical Society*, September, 1931, p. 771. [A-1]

At the invitation of the Royal Aeronautical Society, Dr. Hoff delivered this lecture before the March 19 meeting of

(*Continued on next left-hand page*)

Notes and Reviews

Continued

the Society, covering the work of the Deutsche Versuchsanstalt für Luftfahrt, that is, the German Aeronautical Research Institute.

Dr. Hoff outlines briefly the development of the organization since its foundation in 1912 and discusses at length the range of the work, which includes two chief branches. The older province is the examination and licensing of German aeronautical construction. The D. V. L. is now the examining institution of Germany for all aeronautic material, and the work of the department includes the certifying of types, the examination of construction and design built according to approved type certificates, and the later revision of licensed aeronautic construction and design.

The other sphere of work of the D. V. L. is aerotechnical research. The organization possesses a number of technical installations, laboratories and other research equipment. The article deals with the more important problems on which each of the research departments is now working.

Ergebnisse von Messungen Vertikaler Windgeschwindigkeiten in der Atmosphäre. By K. O. Lange. Published in *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, Sept. 14, 1931, p. 513. **[A-1]**

In view of the importance of vertical air currents in flight, and especially in sailing flight, a systematic investigation was made in this field by the Rhön-Rossitte-Gesellschaft. Soaring balloons, light aircraft and sailplanes were used, and among the factors investigated were the influence of land formation on the nature and velocity of such currents, the relation to temperature distribution, and the variation at different times of day and in the presence of various cloud formations. Observations were made at altitude as well as near the earth's surface.

The conditions under which vertical air currents may be of critical importance to an airplane in flight are pointed out. These disturbances must also be taken into account in the selection of a flying-field, states the author, who sets forth several general rules that must be observed in this respect.

Dynamische Bruchversuche mit Flugzeugbauteilen. By Heinrich Hertel. Published in *Zeitschrift für Flugtechnik und Motorluftschiffahrt*, Aug. 14, p. 465, and Aug. 28, 1931, p. 489. **[A-1]**

The object of the present report of the German Institute for Aeronautical Research is to show the importance of dynamic strength tests of complete airplane parts and the influence of the form of the completed structure on strength characteristics and to contrast metal and wood in these respects.

Test equipment and procedure and methods of evaluating results are described and the accuracy of results obtained by them verified. A report is then given of dynamic tests to rupture of about 10 metal, steel and duralumin spars and 2 wood spars. The wood spars showed no decrease in strength as compared with the values obtained from test pieces. On the other hand, the metal spars exhibited only a fraction of the durability to be expected from the materials used, because of accumulated local stresses far in excess of the average stress calculated. The good results with the wood spars are attributed to the suitable construction methods used to avoid local stresses. Local stresses in the metal spars are attributed to sharp changes in cross-section area, especially in riveted sections, and the unfavorable effect of machining on the characteristics of the finished parts.

To what extent the dynamic strength of metal spars can be improved through suitable construction methods is said to present a field for further research, and the German Institute for Aeronautical Research has undertaken a systematic investigation on this subject.

Adaptation Directe du Groupe Motopropulseur par la Méthode Graphique à Echelles Logarithmiques. By G. Bilbault. Published in *L'Aéronautique*, August, p. 283, and September, 1931, p. 321. **[A-1]**

Adaptation of the engine-propeller group to specific aircraft conditions by the classical method is said to be laborious and to yield only approximations. A graphical method based on the Eiffel-Rith logarithmic system is here presented. According to the claims set forth, it makes possible the development of a set of propellers, and the choice of the most suitable one, in a few minutes, practically without calculation and with great exactitude.

In the first part of the article, the author explains the basis of the theory and gives for each elementary problem treated a chart which summarizes and explains it. In the second part, he briefly examines possible problems of adaptations and treats

(Continued on next left-hand page)

7 PISTON RING COMBINATIONS *for* AUTOMOTIVE ENGINEERS

The Emblem of Sealed Power

THE PISTON RING COMPANY • MUSKEGON MICHIGAN

Notes and Reviews

Continued

with numerical examples four cases constantly encountered in practice.

The Prevention of Ice Formation on Gasoline Tank Vents. By Theodore Theodorsen and William C. Clay. Technical Note No. 394. Published by the National Advisory Committee for Aeronautics, City of Washington, October, 1931; 7 pp., 14 figs. **[A-4]**

A Simultaneous Radio-Telephone and Visual Range-Beacon for the Airways. By F. G. Kear and G. H. Wintermute. Published in the *Bureau of Standards Journal of Research*, August, 1931, p. 261. **[A-4]**

Increased use of the airway radio services by transport operators has resulted in a demand for continuous range-beacon service. At the same time, the broadcasting of weather information has increased in importance and the interruptions to the beacon service have become more frequent. To eliminate difficulties arising from this conflict, a transmitting system has been developed which provides simultaneous transmission of visual range-beacon and radio-telephone signals.

This system is designed to employ existing equipment as far as possible. By combining two transmitting sets into one, the cost of buildings and antenna equipment is reduced. Continuous check on the operation of both systems can be obtained with less personnel than is required at present.

The equipment on the airplane to receive this service is changed only by the addition of a small filter unit which keeps the low-frequency reed voltages from reaching the head telephones and the voice frequencies from the reed indicator. The distance range is the same as that provided by the present visual range-beacon service.

Numerous flight tests of the system have shown it to provide very satisfactory service under adverse interference conditions.

Noise. By A. H. Davis. Published in *The Journal of the Royal Aeronautical Society*, August, 1931, p. 676. **[A-4]**

Mr. Davis considers the various aspects of the problem of reducing noise in and from airplanes. He states that, at present, noise levels in commercial machines, stated in terms of the energy level of an equally loud note of standard pitch, range from 75 to 80 decibels above threshold in the quietest airplane tested, to 110 decibels in a cabin in the plane of airscrews of a noisy one. Persons can converse in a noise level of 85 to 90 decibels above threshold on the scale, and when the level falls to 75 to 80 decibels, conversation can be carried on without great difficulty.

A study of the airscrew, engine exhaust and engine clatter as sources of noise indicates that airscrews, when of high speed, are the dominant cause. Conditions favorable for reduction of airscrew noise are reduced speed, larger diameter, thin section and so forth. The clatter and noise of an engine seem to be of the same order of magnitude above threshold as an airscrew of moderate speed. Experiments suggest that airscrew noise can be reduced, and accordingly engine and exhaust noise demand attention. Probably something can be done by interposing wings as a screen between, say, the exhaust and the cabin, or by enclosing the engine. Some degree of exhaust silencing can be achieved by a simple perforated pipe. Further silencing may involve increased back pressure. The silencing of engines, either by enclosing them or, if possible, re-designing camshafts and other parts, to modify their motion, seems desirable.

CHASSIS PARTS

Turbine Clutch Smooths Car Operation—Reduces Stresses and Fatigue Failures. By Joseph Jandasek. Published in *Automotive Industries*, Sept. 12, 1931, p. 396. **[C-1]**

The author insists that the increasing interest in turbine power transmitters makes it necessary for automotive engineers to familiarize themselves with the subject; therefore he illustrates and explains the fundamental theory of turbo clutches and gives information about existing patents.

The new turbo mechanism is defined as a combination of a pump impeller and a turbine runner, forming a slipping clutch through which torque and energy from a high-speed engine or other prime mover can be transmitted.

In conclusion, Mr. Jandasek lists the following among the chief advantages of the turbine clutch: steady torque; perfectly smooth starting and low-speed running; absence of shuddering, "hesitation," shocks and jerks, and consequent lowering of maximum stresses and reduction of fatigue failures.

(Continued on next left-hand page)

Notes and Reviews

Continued

Contact Stresses in Gears. By R. V. Baud. Published in *Mechanical Engineering*, Sept., 1931, p. 667. **[C-1]**

Previous researches by this author have been reported in *Mechanical Engineering*. The latest of these Mr. Baud refers to as concerned chiefly with the fillet stresses for different positions of contact, one tooth carrying the total load. After the fillet stresses were studied, the author thought it advisable to use the same experimental set-up in carrying out some preliminary work on contact stresses, the results of which are given in the present paper.

The object of this additional work was threefold: (*a*) to compare the experimental data with the data obtained by the use of the equations previously derived; (*b*) to compare the magnitude of contact stresses with fillet stresses; and (*c*) to obtain approximate information about the complete stress field in a gear tooth.

Les Engrenages à Vis sans Fin. By Paul Durand. Published in *Journal de la Société des Ingénieurs de l'Automobile,* July, August, September, 1931, p. 1456, d., p. 1470. **[C-1]**

Worm gearing, although possessing important theoretical advantages, has been little used in the past, asserts the author, because of difficulties in connection with the material and the production methods. In this article he describes steps taken to overcome these difficulties. They consist of using, as material, a base of steel over which is laid a thin coating of bronze, and of developing cutting and rectifying machines which conform to the theoretical requirements set forth. These machines are of French design and manufacture. Examples are given of the applications of worm gearing to automotive usage. In the discussion, further examples are cited, information is given on the efficiency and lubrication of the gears, and possible objections to worm gearing are answered.

Le Freinage sur Route Mouillée. By Henri Petit. Published in *Journal de la Société des Ingénieurs de l'Automobile,* July, August, September, 1931, p. 1450. **[C-1]**

Two charts showing the variation of negative acceleration with speed during braking are presented. The figures on which they are based were obtained from the brake tests of the Critérium International de Tourisme Paris-Nice. One chart represents the results of the 1930 tests on dry macadam; the other those of the 1931 tests made on the same pavement when wet. The method followed is to have the cars start at a given line, accelerate to another, where the brakes are applied, and measure the speed for 40 ft. prior to the application of the brakes and the stopping distance thereafter.

On the dry pavement, negative acceleration increased with speed, whereas on the wet road it decreased, although not to as great an extent as was expected. The author concludes from his findings that wet-weather driving is not so dangerous as has been popularly supposed. He cites further tests made by English experimenters from which he concludes that tires presenting but a small surface in contact with the road have better adherence in wet weather than have tires with more extensive surface contact.

Welding Automobile Wheels. By C. L. Eksergian. Published in *American Machinist,* Sept. 17, 1931, p. 459. **[C-5]**

This paper covering the present status of welding stresses the turning point between the old form of welding and modern methods; that is, the change from skilled artisans to highly mechanized processes. Mr. Eksergian makes a critical survey of flash, butt, projection, spot and arc automatic welding in the manufacture of steel automobile wheels.

ENGINES

Detonation, Spark-Plug Position and Engine Speed. By R. O. King and H. Moss. Published in *Engineering,* Aug. 7, 1931, p. 177. **[E-1]**

The Ricardo E. 35 variable-compression engine of the overhead-valve type was used for the experiments made to determine especially the usable compression-ratio and the corresponding power developed depending on whether the spark-plug position causes the flame movement to be toward the exhaust valves or the cooler inlet valves.

The relation between detonation and direction of flame movement was found, in the early stages of the experiments, to be involved with the effect of engine speed.

The test results are discussed at length under three sections: Effect of Reversal of Flame Movement on H.U.C.R. Fixed Ignition 30-Deg. Advance; Effect of Flame Movement Reversal and

(*Continued on next left-hand page*)

Notes and Reviews

Continued

Ignition Timing on Detonation and Power (b.m.e.p.); and Effect of Flame Reversal and Ignition Timing on B.M.E.P. at Fixed Compression-Ratios.

Stroke-Bore Ratio. By G. Sartoris. Published in *The Automobile Engineer*, Sept., 1931, p. 339. [E-1]

This paper presents a consideration of the effect of stroke-bore ratio upon power-weight ratio and points out that experimental work on the possible advantages of lower stroke-bore ratios has been discouraged in England by the system of motor-car taxation.

A Decade of Light-Weight Diesel Development in Europe. By J. O. Huse. Paper presented before the National oil and gas-power meeting of the American Society of Mechanical Engineers at Madison, Wis., June, 1931. [E-1]

Diesel-engine manufacturers of the world have for a decade engaged in the development of a light, high-speed engine. They have been encouraged by the success of war-time light-weight submarine Diesels, aided occasionally by government subsidy, attracted by the great sales possibilities of automotive and locomotive powerplants, forced by necessity to expand because of over-competition in the heavy-duty fields, and are cognizant of the inherent worth of the Diesel engine as a prime mover.

The general observations in this paper are based on a table giving the principal design factors or characteristics of 40 modern four-cycle high-speed light-weight European engines designed by 17 manufacturers. The minimum size is 35 hp. per cylinder, and the maximum 235 hp. None of the engines weighs more than 30 lb. per hp. complete.

The author shows the progress since 1920 of the four-cycle high-speed Diesel above 35 hp. per cylinder. Automotive developments below 35 hp. were discussed by the author in the *Journal of American Society of Naval Engineers*, vol. XLI, No. 4, Nov., 1929.

Das Klopfen von Zündermotoren. By Kurt Schnauffer. Der 251 Bericht der Deutschen Versuchsanstalt für Luftfahrt. (Report No. 251 of the German Institute for Aeronautical Research.) Published by the Deutsche Versuchsanstalt für Luftfahrt, Berlin, Germany; 4 pp.; 9 illustrations. [E-1]

In its investigation of the nature of detonation, the German Institute for Aeronautical Research has used two electrical instruments, one of which makes possible the determination of the course of pressure variations in the cylinder, while the other, based on the principle of ionization during combustion, permits the tracing of flame movement and spread.

Among the conclusions drawn are that, in detonation, the last portion of the charge to burn is highly compressed and ignites instantaneously when its self-ignition temperature is reached; this instantaneous ignition gives rise to decided increases in pressure and temperature; sharp local pressure differences are also caused, which tend to equalize themselves with great speed; the intensity of detonation depends upon the amount of charge unburned when detonation sets in and upon its mixture ratio; either the pressure rise at the center of detonation or the mixture ratio of that part of the charge which ignites instantaneously may be chosen as a measure of detonation; for this purpose the pressure rise must be measured at the center of detonation; besides detonation proper, three other types of knocking may be distinguished; the higher temperatures caused by detonation give rise to a greatly increased ionization; in the case of extreme detonation no after-burning occurs and if the amount of fuel charge ignited instantaneously is very great a negative flame-front velocity is set up.

Zur Kurzstreckenmessung des Brennstoffverbrauches im Bewegten Fahrzeug. By Heinrich Straubel. Published in *Automobiltechnische Zeitschrift*, Aug. 20 and 31, 1931, p. 519. [E-1]

Previously used methods of making fuel-consumption tests on vehicles on the road are criticized on the grounds of inaccuracy and the requirement of long test runs which, the author states, yield only rough average results that are not reproducible and are subject to the influence of many uncontrollable factors.

Test apparatus and methods designed to overcome these defects are described. By following this procedure, only short runs are said to be required, small quantities of fuel can be measured with extreme accuracy and subjective errors of observation are avoided by the photographic recording of results.

Tests of the apparatus which are said to show its accuracy over runs as short as a little more than 300 ft. are described.

(Continued on next left-hand page)

Notes and Reviews
Continued

MATERIAL

Influence of Variations in Heat-Treatment and Aging on Duralumin. By A. Von Zeerleder. Paper presented at a meeting of the Institute of Metals, on Sept. 14 and 15, 1931, at Zurich, Switzerland. [G-1]

Experiments showing the influence of the temperature of the quenching liquid and the temperature of aging on the physical properties of duralumin (Avional) were made. The author states that quenching in hot water or in oil causes less deformation and that, if the temperature of the quenching medium as well as the aging temperature be 50 deg. cent. (122 deg. fahr.), the quenching and aging have no disadvantageous influence on the physical properties. On the contrary, measurements of the electrochemical potential, electrical conductivity, tensile and corrosion properties showed that a temperature of 145 deg. cent. (293 deg. fahr.) had a decidedly disadvantageous influence. A possible explanation for this phenomenon is to be found in the effect of different annealing temperatures on the potential of aluminum-copper alloys.

Other papers of interest presented at the same meeting are:

Unsoundness in Aluminum Sand-Castings. Part I—Pinholes: Their Causes and Prevention. By D. Hanson and I. G. Slater. [G-1]

Unsoundness in Aluminum Sand-Castings. Part II—The Effect of Using Metals Previously Subjected to Corrosive Conditions. By D. Hanson and I. G. Slater. [G-1]

The Protection of Magnesium Alloys Against Corrosion. By H. Sutton. [G-1]

The Attack on Mild Steel in Hot-Galvanizing. By Edward J. Daniels. [G-1]

Effect of Nitrogen on Steel. By Frank W. Scott. Published in *Industrial and Engineering Chemistry*, Sept., 1931, p. 1036. [G-1]

In the investigation herein reported the effect of nitrogen on steel has been magnified by nitrifying regular 8-ton ingots and comparing the physical properties of the steel with those of the regular product. Nitrogen has been found to have four times the effect of the same quantity of phosphorus. An increase of 0.01 per cent in nitrogen content was sufficient to cause a marked difference in the physical properties of the steel. The coefficient of effect increased with the increase of carbon.

An equation has been derived whereby the effect of an increase of nitrogen on the elongation of the steel can be calculated quite accurately. Also, the equation can be used to indicate the benefits to be derived by using a denitrifying agent.

Crackless Plasticity, a New Property of Metals. By H. F. Moore. Published in *The Iron Age*, Sept. 10, 1931, p. 674. [G-1]

Metals seem to have a property, states this authority, which is neither strength nor ductility as revealed by a tension test and which appears to be important; namely, the ability to resist fairly large numbers of loads that cause very slight plastic action without starting a crack. He offers the term "crackless plasticity" to denote this property. Suggested methods of experimental study of this property include fatigue tests following a period of overstress, notched-bar impact tests and tests of the damping of vibrations in the metal.

Value of Rubber Hydrocarbon in Reclaimed Rubber. By C. W. Sanderson. Published in *Industrial and Engineering Chemistry*, Sept., 1931, p. 989. [G-1]

The investigation reported in this article is concerned with the evaluation of the rubber hydrocarbon of reclaimed rubber as measured by resistance to road wear in a tire-tread stock. The work is a confirmation by road tests of the work reported by Vogt in 1928 under this same title and is similar to previous work by the author.

The Corrosive Effect of Gasolines and Motor Benzols on Copper. By F. H. Garner and E. B. Evans. Published in the *Journal of the Institution of Petroleum Technologists*, July, 1931, p. 451. [G-1]

Considerable attention has been directed in recent years to the corrosive action that certain motor fuels exert upon the metal parts of the fuel systems of automobile and aircraft engines.

Free sulphur has been shown to be an active copper-corroding agent, while certain sulphur compounds containing loosely attached sulphur also cause this formation of sulphide.

The problem of detecting and identifying the corrosive elements, with a view to their elimination and of devising satisfactory tests for the detection of corrosive action and the estimation of the amount of deleterious matter present, is obviously of interest to the refiner and marketer of motor fuels.

(*Concluded on next left-hand page*)

Notes and Reviews

Concluded

A summary of the previously published literature on this subject is given in this paper and is followed by an account of experimental work carried out with the objects of selecting the most satisfactory test for corrosion and devising a convenient and accurate method for the estimation of free sulphur, together with some discussion of the results.

An Investigation of Cotton for Parachute Cloth. By William D. Appel and R. K. Worner. Technical Note No. 393. Published by the National Advisory Committee for Aeronautics, City of Washington, September, 1931; 21 pp. **[G-1]**

Nitriding for the Engineer. By Oscar E. Harder. Published in *Metals and Alloys*, Sept., 1931, p. 132. **[G-5]**

This paper contains a valuable survey of the literature published during the last five years on the subject of nitriding and includes a bibliography of 50 references.

MISCELLANEOUS

Friction Is Independent of Load in Well-Lubricated Bearings. By P. M. Heldt. Published in *Automotive Industries*, Aug. 15, 1931, p. 234. **[H-1]**

Mr. Heldt points out that, in spite of the research work conducted during recent years to ascertain the relationship between the friction in a well-lubricated bearing and the various factors on which it depends, many persons still have a wrong conception of the laws that affect journal bearings. He analyzes the basis of the dimensional theory and shows that the friction coefficient varies directly as the absolute oil viscosity and the angular speed and varies inversely as the bearing load per unit of area.

TRACTOR

The Tractor Field Book. Published by the Farm Implement News Co., Chicago, 1931; 186 pp. **[M-3]**

The 1931 edition of the Tractor Field Book, made available in July, contains not only a complete and uptodate record of the Nebraska tractor tests but a wealth of other data and power farm-equipment specifications.

Personal Notes of the Members

(Continued from p. 420)

Fred C. Hebert is now serving the Snyder Tool & Engineering Co., of Detroit, as a sales engineer. He was previously employed by the Seneca Falls Machine Co., of Seneca Falls, N. Y., in a similar capacity.

H. D. Hollinger has been appointed supervisor of the machine division of Servel, Inc., of Evansville, Ind. He used to be division superintendent for the Ternstedt Mfg. Co., of Detroit.

Herbert W. Houston is now superintendent and part owner of the Pomeroy Co., of Los Angeles, manufacturers of motion-picture equipment. He formerly served the Hughes Development Co., of the same city, as superintendent.

William A. Irvin, having given up his office as vice-president in charge of operations of the American Sheet & Tin Plate Co., of Pittsburgh, has become associated with the United States Steel Corp., in New York City.

Capt. J. S. Irving recently resigned his position as technical director of Humber, Ltd., of Coventry, England, owing to ill health and is taking an extended rest to make a complete recovery, which he expects in the very near future.

Having resigned his position as associate editor of *Railway Age,* **E. Leslie Jacobus** has accepted a position as engineer with the Ethyl Gasoline Corp., and is located in Atlanta, Ga.

Maurice L. Kerr has relinquished his position as chief engineer of the Brockway Motor Truck Corp., of Cortland, N. Y., and now holds a similar position with the Indiana Truck Corp., of Marion, Ind.

Stephen Lester Kerr has been elected president of the Carbureter & Electrical Service Co., of Seattle, Wash. His former connection was with the Covey Motor Co., of Salt Lake City, Utah, as general manager.

E. H. Kimball is now a director of industrial education at West High School, Waterloo, Iowa. He used to be mechanical engineer for the John Deere Tractor Co., of the same city.

J. M. Klements has given up his position as body-layout draftsman with the Pierce-Arrow Motor Car Co., of Buffalo. He now holds a similar position with the Chrysler Motor Car Co., of Detroit.

Howard W. Linkert, who was chief engineer for the Wheeler-Schebler Carburetor Co., of Indianapolis, is now president of the Langsenkamp-Linkert Carburetor Co., Inc., also of that city.

William S. Marsden was recently appointed field representative of the Ethyl Gasoline Corp., of New York City, and is located at Allentown, Pa. His previous connection was with the Pure Oil Co., of New York City, as industrial engineer.

Harry Austin Murray has formed a connection with the American Airplane & Engine Co., of Farmingdale, N. Y., as aeronautic maintenance engineer. Last year he was a student at the Massachusetts Institute of Technology.

The Franklin Illinois Co., of Chicago, has engaged **C. Maynard Parsons** as service manager. Before forming this connection, Mr. Parsons was in the dealers' business administration division of the Franklin Automobile Co., of Syracuse.

Walter S. Peper, formerly sales engineer of the Bellanca Aircraft Corp., in New York City, is now an account executive for the Stewart Davis Advertising Agency, of the same city.

J. Otis Pierce, formerly vice-president and sales manager of the Brown-Lipe Gear Co., of Syracuse, N. Y., now a subsidiary of the Spicer Mfg. Co., of Toledo, Ohio, has severed his connection with that company.

John Pollitt, Jr., formerly proprietor of Pollitt & King, of Liverpool, England, is now service garage manager for Joseph Lucas, Ltd., of Birmingham, England.

Leland S. Prior, Jr., has severed his connection with the Aero Engineering & Advisory Service, of New York City, which he served as resident engineer for Northern California, to manage the ground school at San Mateo, Calif., for the Curtis-Wright Flying Service.

(Concluded on next left-hand page)

Personal Notes of the Members

Concluded

Arthur R. Prouty began his new duties in September as engineer with the Russell Mfg. Co., of Middletown, Conn. His previous connection was with the Mack-International Motor Co., of New York City, in the same capacity.

Allen Quimby, Jr., has been engaged by Barron G. Collier, Inc., of New York City. He was formerly connected with the Street Railways Advertising Co., of the same city.

Ralph N. Robertson, lately chief mechanical engineer for the Blaw Knox Co., of Pittsburgh, is now affiliated with the Atwood-Bradshaw Corp., of the same city.

W. C. Robbins, former chief engineer of the Houde Engineering Corp., of Buffalo, and for the last two years vice-president in charge of engineering and manufacturing of the Gabriel Snubber Mfg. Co., of Cleveland, is now vice-president and general manager of the Thermo Hydraulic Shock Absorber Co., of Cambridge, Mass.

Having resigned as vice-president and general manager of the Oliver Farm Equipment Co., of Chicago, **R. C. Rolfing** is now general works manager of the Grigsby-Grunow Co., also of Chicago.

Samuel E. Rusinoff, formerly mechanical designer of the National Lock Washer Co., of Newark, N. J., is now purchasing engineer in the machine-tool-building division of the Amtorg Trading Corp., at New York City, commercial representative of the Soviet in this Country.

James N. Scully, who was treasurer of the Houdaille Co. from 1920 to 1926, is a director of the Thermo-Hydraulic Shock Absorber Co., of Cambridge, Mass.

B. S. Shenstone is now connected with the Supermarine Aviation Works, Ltd., at Southampton, England. He formerly worked for the Junkers Flugzergwerk, A. G., at Dessau, Germany.

E. B. Sherrick is now layout draftsman for the Cadillac Motor Car Co., of Detroit. His previous position was that of designer with the Detroit Aircraft Co., of that city.

James M. Shoemaker was recently appointed assistant aeronautic engineer with the National Advisory Committee for Aeronautics, at Langley Field, Va. This is a change from his former post as lecturer on aeronautic engineering at the University of Southern California, in Los Angeles.

George R. Strohl now serves the Autocar Co., of Ardmore, Pa., as special equipment engineer. Previously he was connected with the factory of the International Motor Co. at Allentown, Pa.

Harry Strohm, formerly sales engineer of the Wheeler-Schebler Carburetor Co., of Indianapolis, is now connected in the same capacity with the Bendix-Stromberg Carburetor Co., of Detroit.

Stanley John Swift has left the Russell Mfg. Co., of Middletown, Conn., which he served as sales representative in Toledo, Ohio, and is now connected with the organization of J. Becker & Sons, at Albany, N. Y.

Stephen B. Tompkins recently became connected with the Autocar Sales & Service Co., of Chicago. His former position was that of engineer in charge of special equipment and sales for Fred L. Merkel, of Chicago.

George H. Tucker, formerly president and general manager of George H. Tucker, Inc., of Seattle, Wash., is now secretary and manager of the Minor Avenue Motor Service, of the same city.

Charles A. Viriot, managing director of Flertex, of Neuilly, France, announced that he would sail for America in October for the purpose of forming connections for the production or distribution in Europe of automobile equipment and accessories, particularly friction products. His address while in this Country is care of J. E. Bernard & Co., New York City.

Ernest von Mertens is now engineer for the Scintilla Magneto Co., of Sidney, N. Y. He was formerly assistant superintendent of the Apollo Magneto Co., of Kingston, N. Y.

Leroy B. Voshall, formerly a student at Virginia Polytechnic Institute, Blacksburg, Va., now works for the Texas Co., of New York City, as research engineer.

W. Henry Wyckoff recently entered the employment of the Chrysler Motor Co., of Detroit, as a draftsman. He was formerly employed on tractor-engine layout and detail work for the Cheliabinsk Tractor Co., of Detroit.